Chapter 8

Photosynthesis

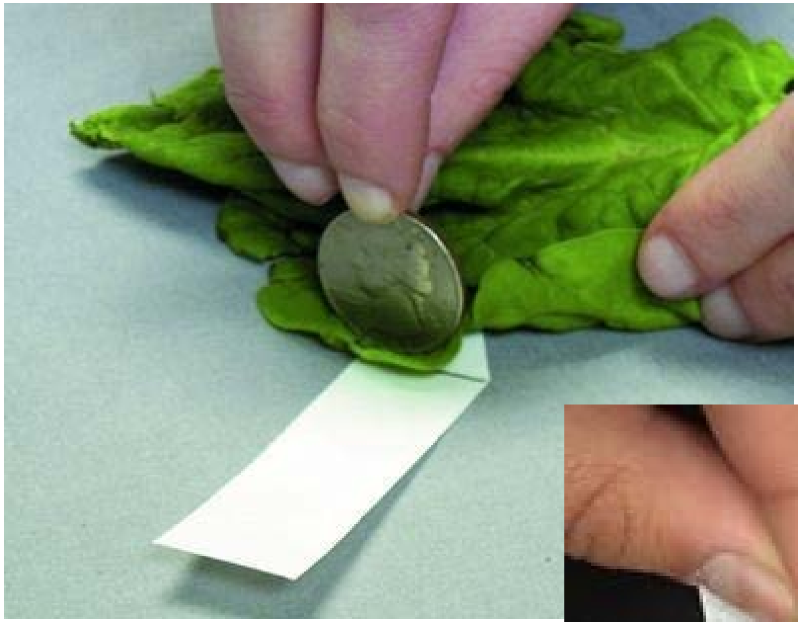
Warm-Up

1. Compare and contrast heterotrophs to autotrophs.

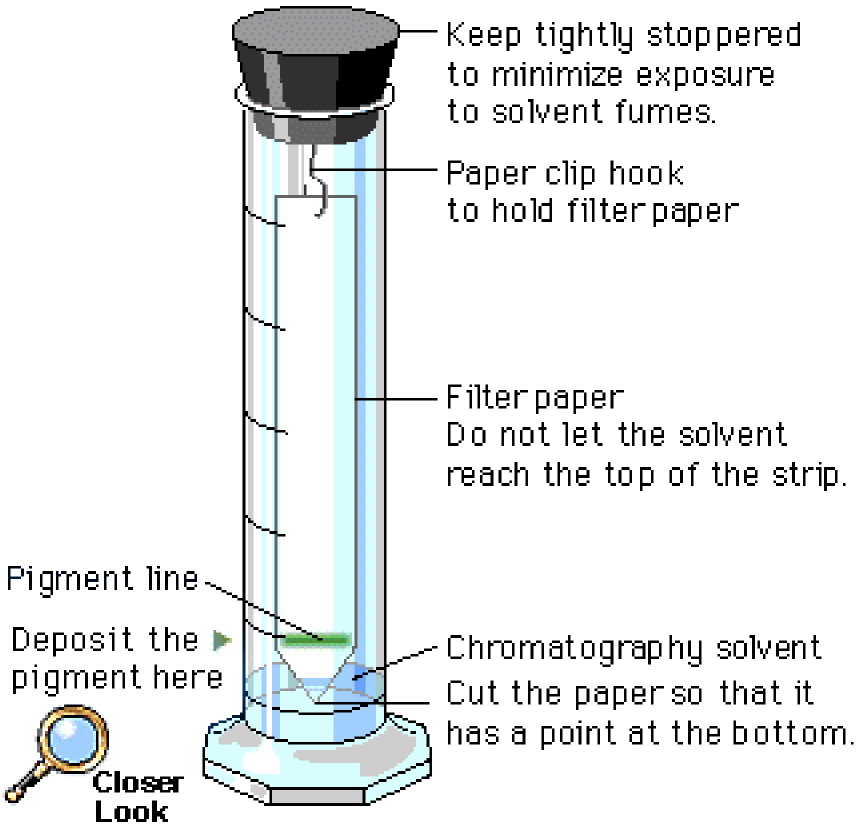
2. Write the balanced chemical equation for photosynthesis.

3. Why is the leaf shaped and structured as it is? *(think structure → function)*

Apply Leaf Pigments to Chromatography Paper



Paper Chromatography



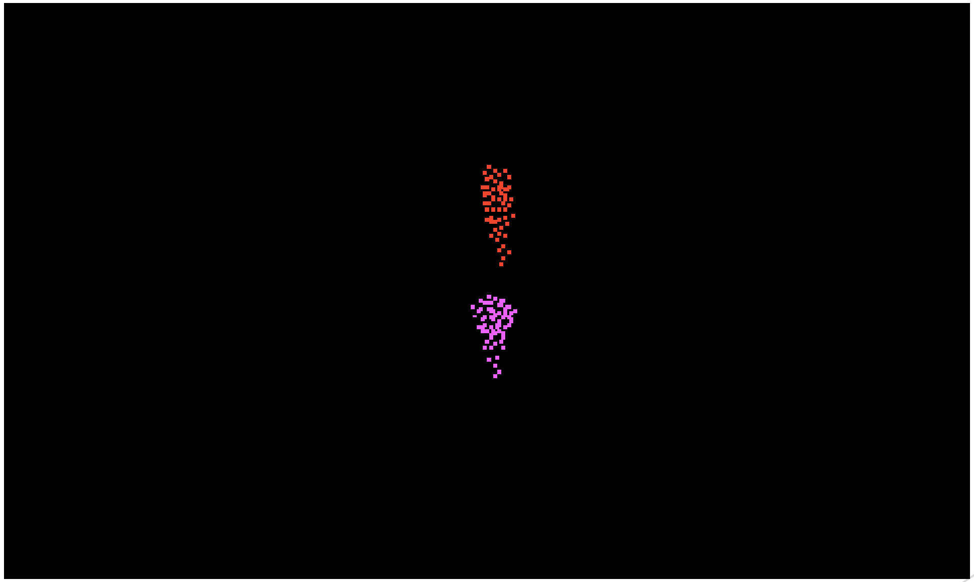
Be sure the tip of the filter paper touches the solvent, but keep the pigment line above it.

Calculating R_f Values

R_f = (distance pigment moved) / (distance solvent front moved)

Red Pigment: $R_f = 57/66 = 0.86$

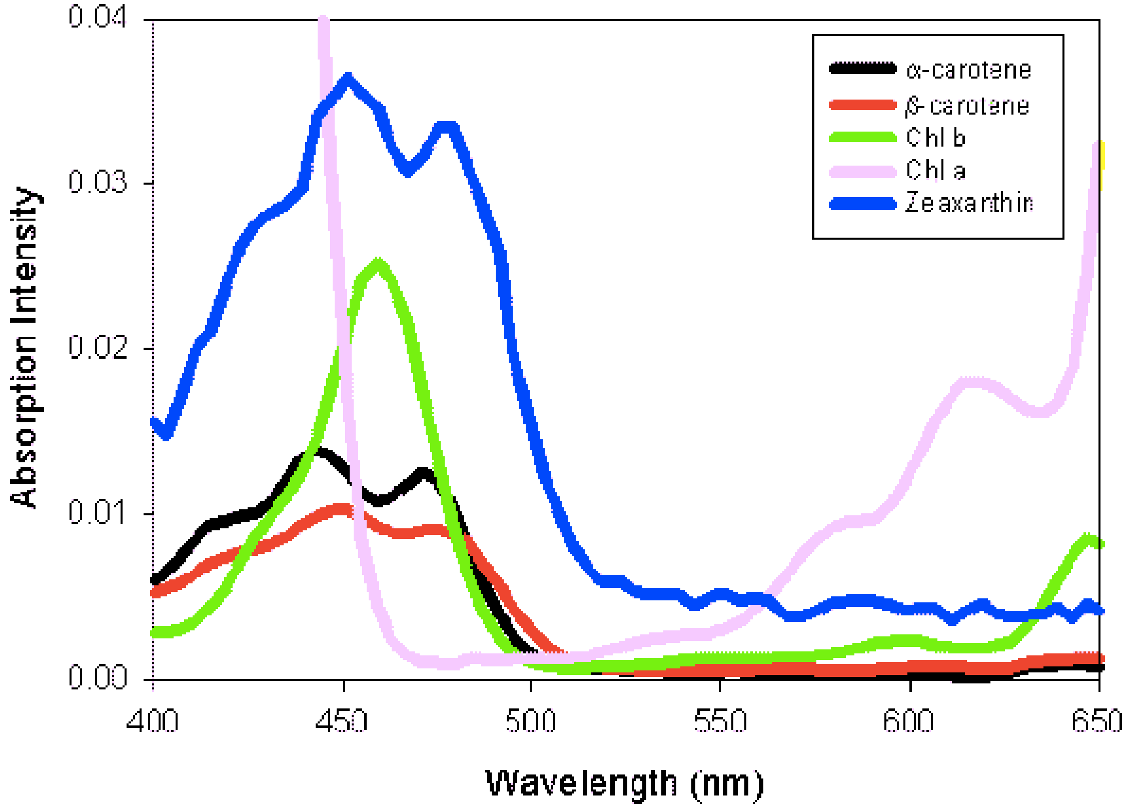
Purple Pigment: $R_f = 32/66 = 0.48$



Warm-Up

1. What pigments are found in spinach leaves?
2. Based on the color of the pigments, what wavelengths of visible light are absorbed by each of these pigments? (see Figure 10.7 in textbook for help)

Warm-Up



Which wavelengths of light are best absorbed by each pigment shown in the graph?

Warm-Up

1. A photon of which color of light would contain more energy:
   - Orange (620 nm) or Blue (480 nm)?
   - Why?

2. How did Engelmann determine the absorption spectrum for algae? What were his results?

3. Read the article about leaves in the fall. What is happening in the leaves during autumn?

Warm-Up

1. Draw the chloroplast and label it. Where does the light reaction, Calvin cycle, chemiosmosis occur?

2. What is RuBP, rubisco and G3P?

3. Compare Respiration to Photosynthesis.

Warm-Up

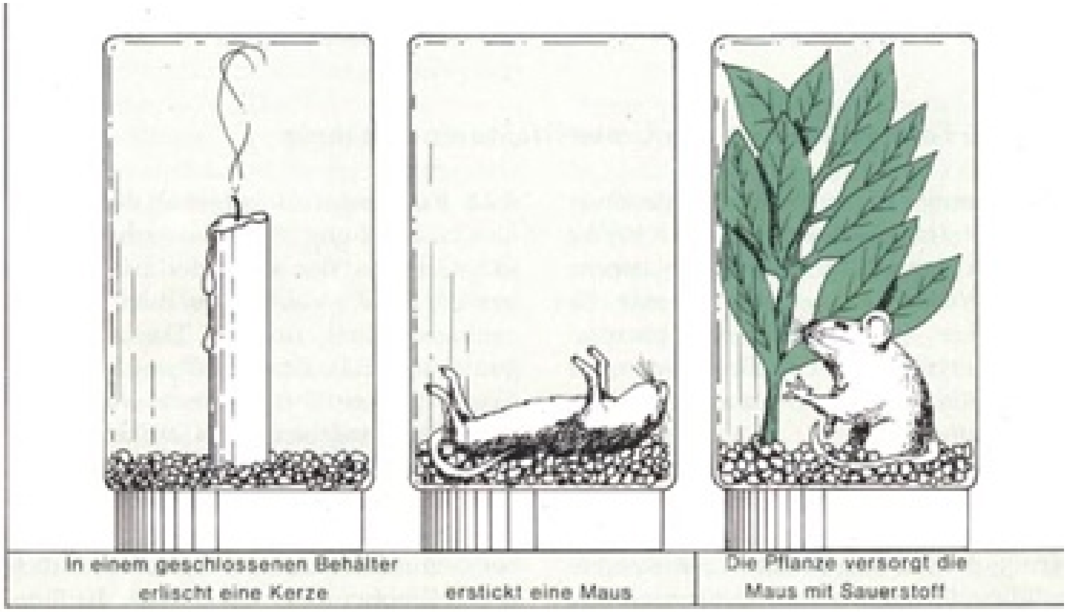
1. Why do C_4 plants photosynthesize without photorespiration?

2. What is the purpose of the proton gradient?

3. State the differences and similarities between C_4 and CAM plants.

Explain the results of each experiment

Experiment A Experiment B Experiment C



Chapter 8
Photosynthesis

What you need to know:

- The summary equation of photosynthesis, including the source and fate of the reactants and products.
- How leaf and chloroplast anatomy relate to photosynthesis.
- How photosystems convert solar energy to chemical energy.
- How linear electron flow in light reactions results in the formation of ATP, NADPH, and O_2.
- How the formation of a proton gradient in light reactions is used to form ATP from ADP plus inorganic phosphate by ATP synthase.
- How the Calvin cycle uses energy molecules of the light reactions (ATP and NADPH) to produce carbohydrates (G3P) from CO_2.

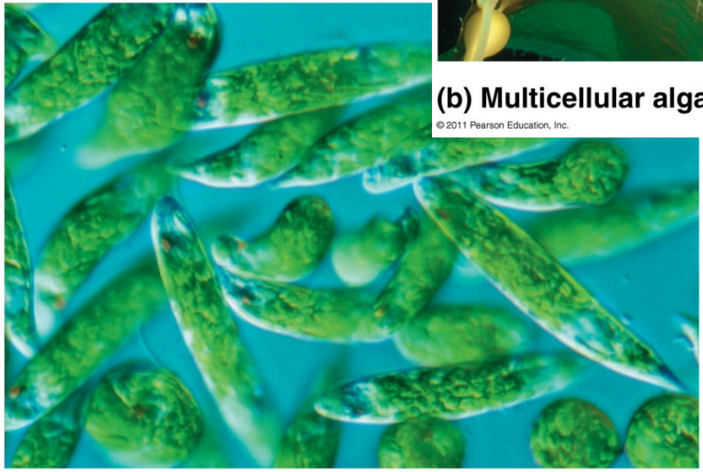
Photosynthesis in Nature

- Plants and other autotrophs are producers of biosphere
- Photoautotrophs: use light E to make organic molecules
- Heterotrophs: consume organic molecules from other organisms for E and carbon

Photoautotrophs

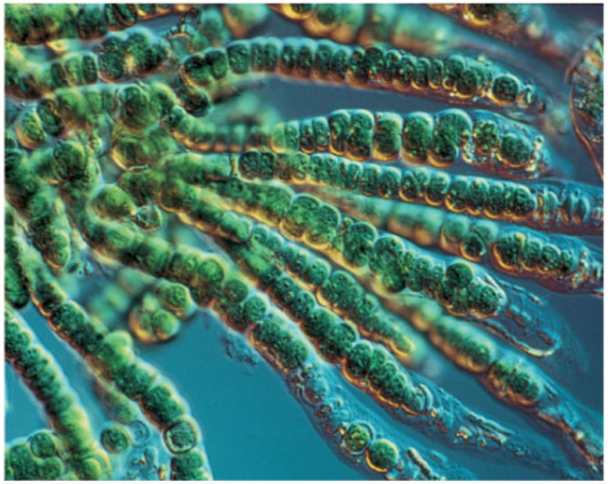
(a) Plants

(b) Multicellular alga



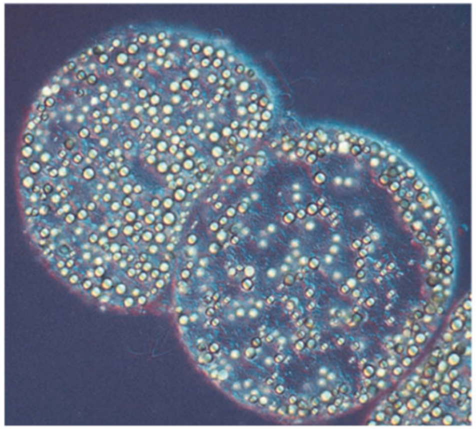
(c) Unicellular protists

10 μm



(d) Cyanobacteria

40 μm



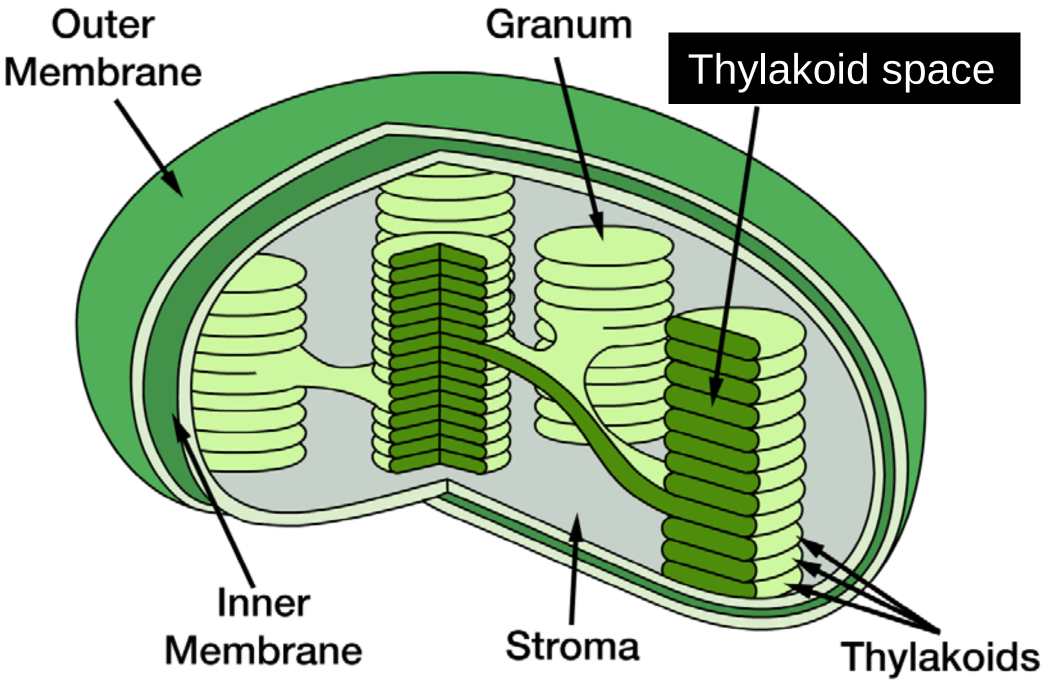
(e) Purple sulfur bacteria

1 μm

Photosynthesis: Converts light energy to chemical energy of food

- Chloroplasts: sites of photosynthesis in plants

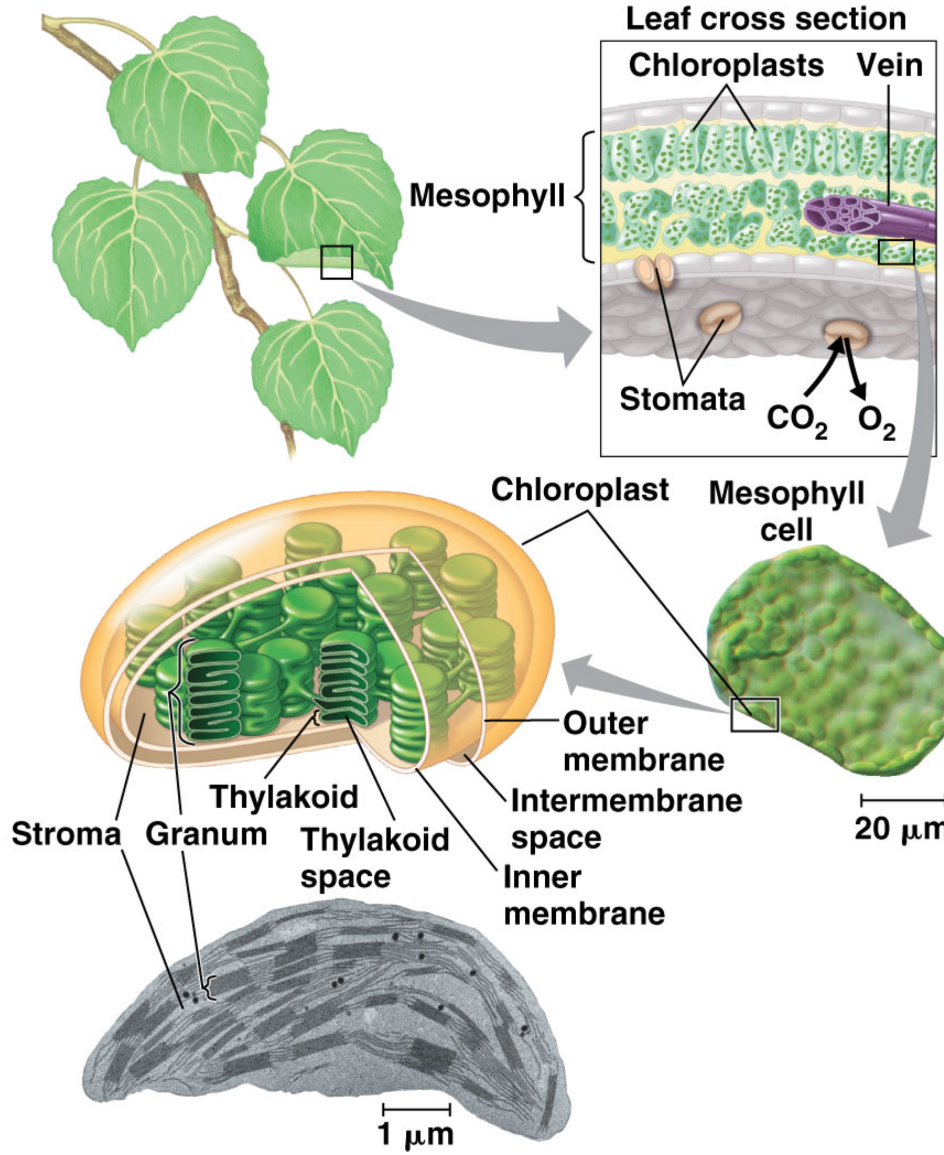
Chloroplast




the chloroplast
genomics digital lab
www.vivetechnologies.com

Sites of Photosynthesis

- **mesophyll**: chloroplasts mainly found in these cells of leaf
- **stomata**: pores in leaf (CO_2 enter/O_2 exits)
- **chlorophyll**: green pigment in thylakoid membranes of chloroplasts



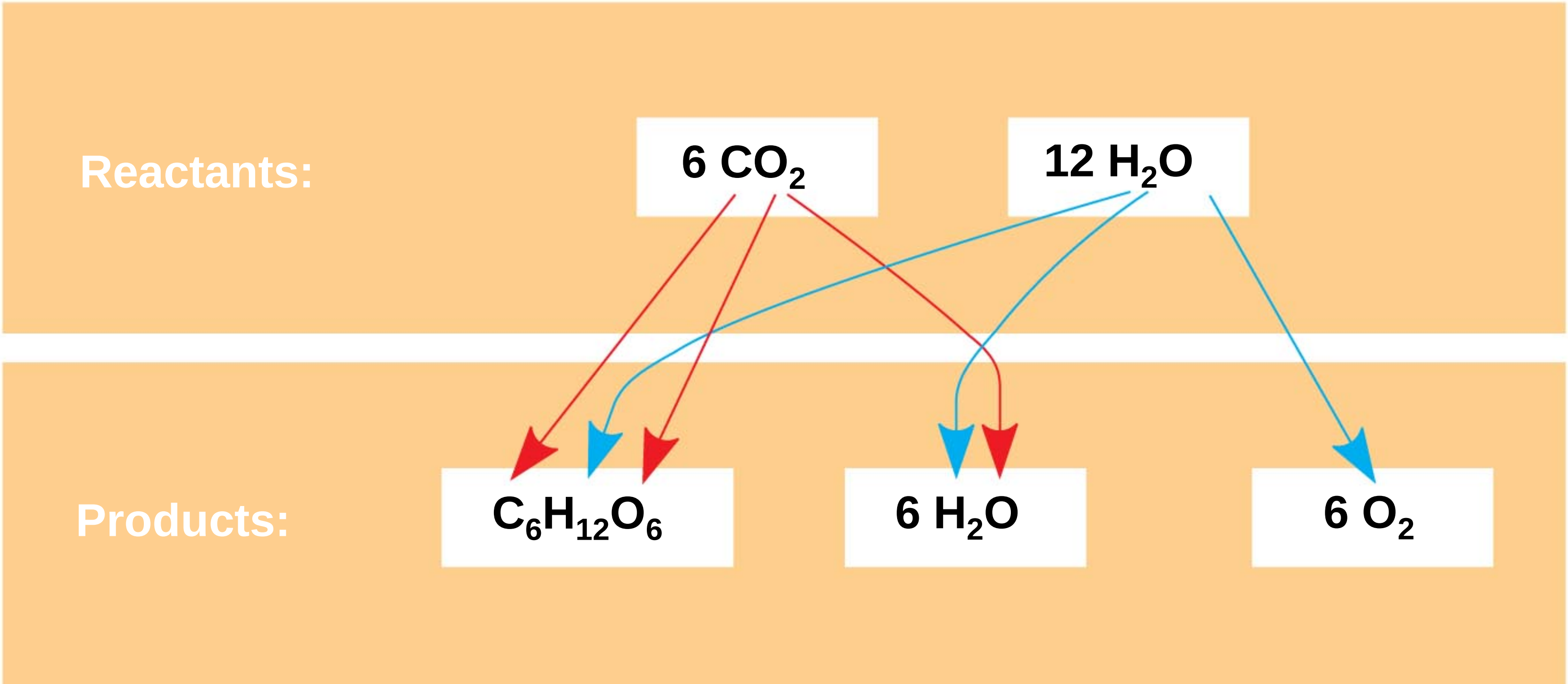
Photosynthesis

$6CO_2$ + $6H_2O$ + Light Energy → $C_6H_{12}O_6$ + $6O_2$

- Redox Reaction:
  - Water is split → e^- transferred with H^+ to CO_2 → sugar
- Remember: OILRIG
  - Oxidation: lose e^-
  - Reduction: gain e^-

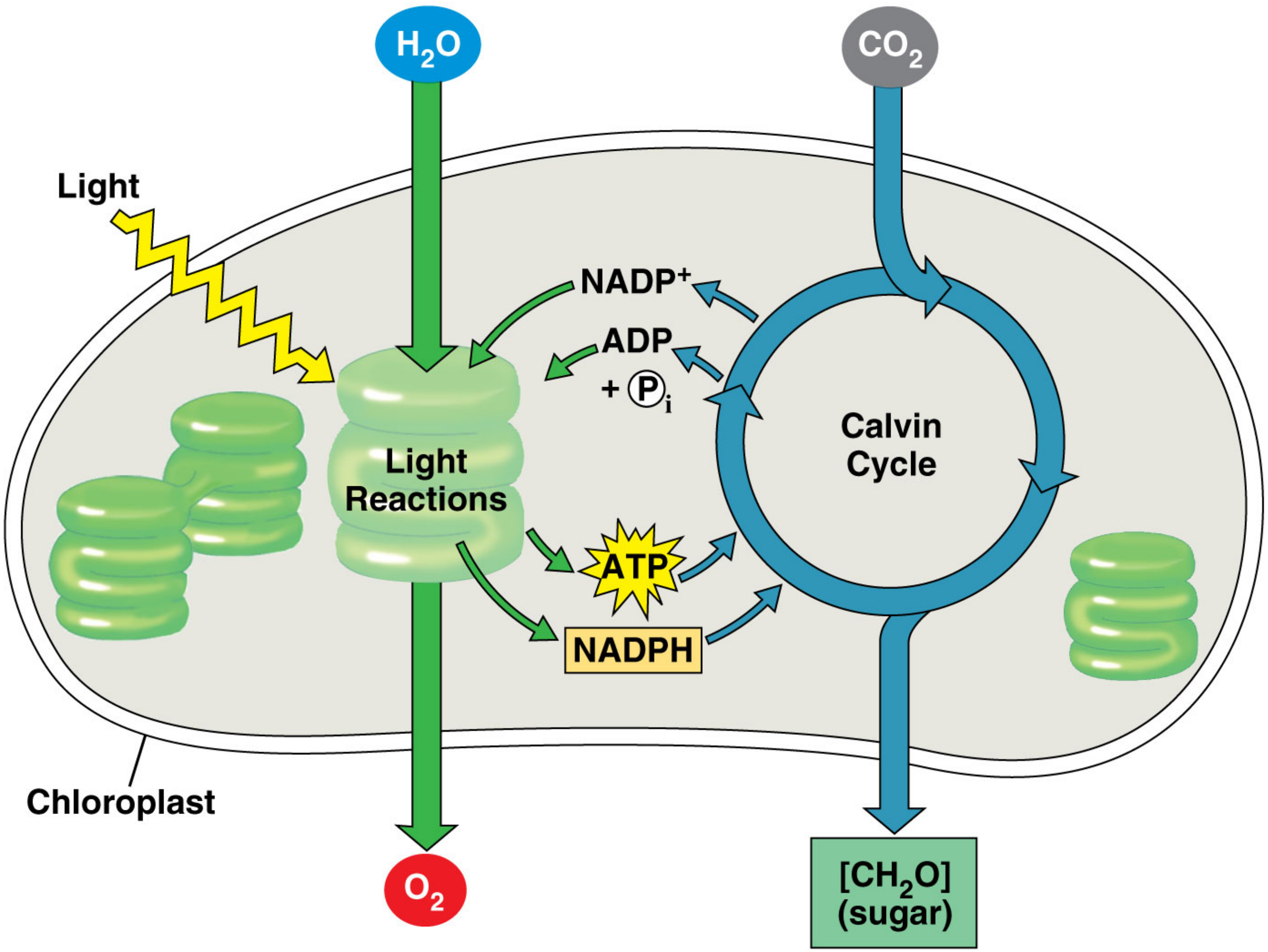
Tracking atoms through photosynthesis

- Evidence that chloroplasts split water molecules enabled researchers to track atoms through photosynthesis (C.B. van Niel)



Photosynthesis = Light Reactions + Calvin Cycle

"photo" *"synthesis"*

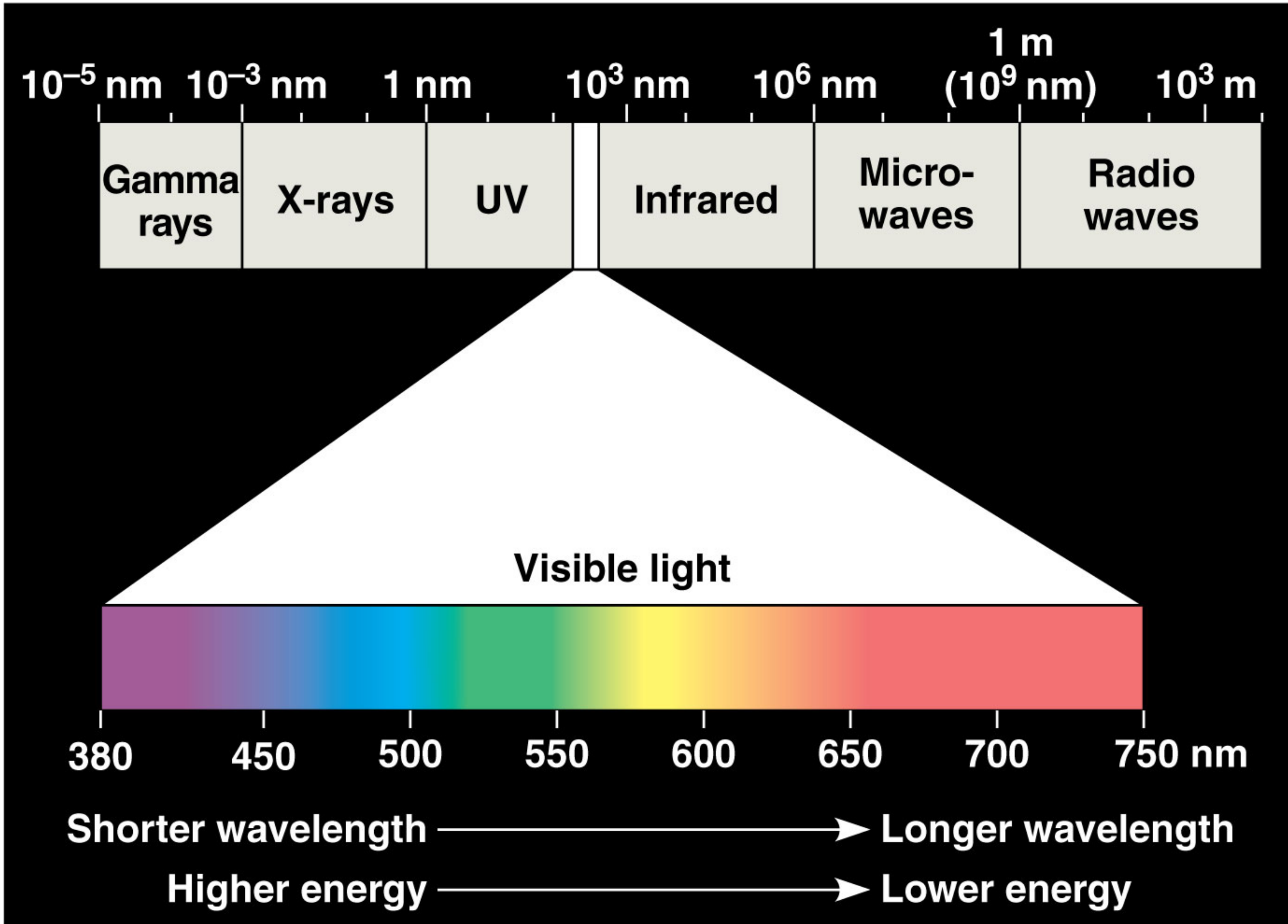


Light Reactions: Convert solar E to chemical E of ATP and NADPH

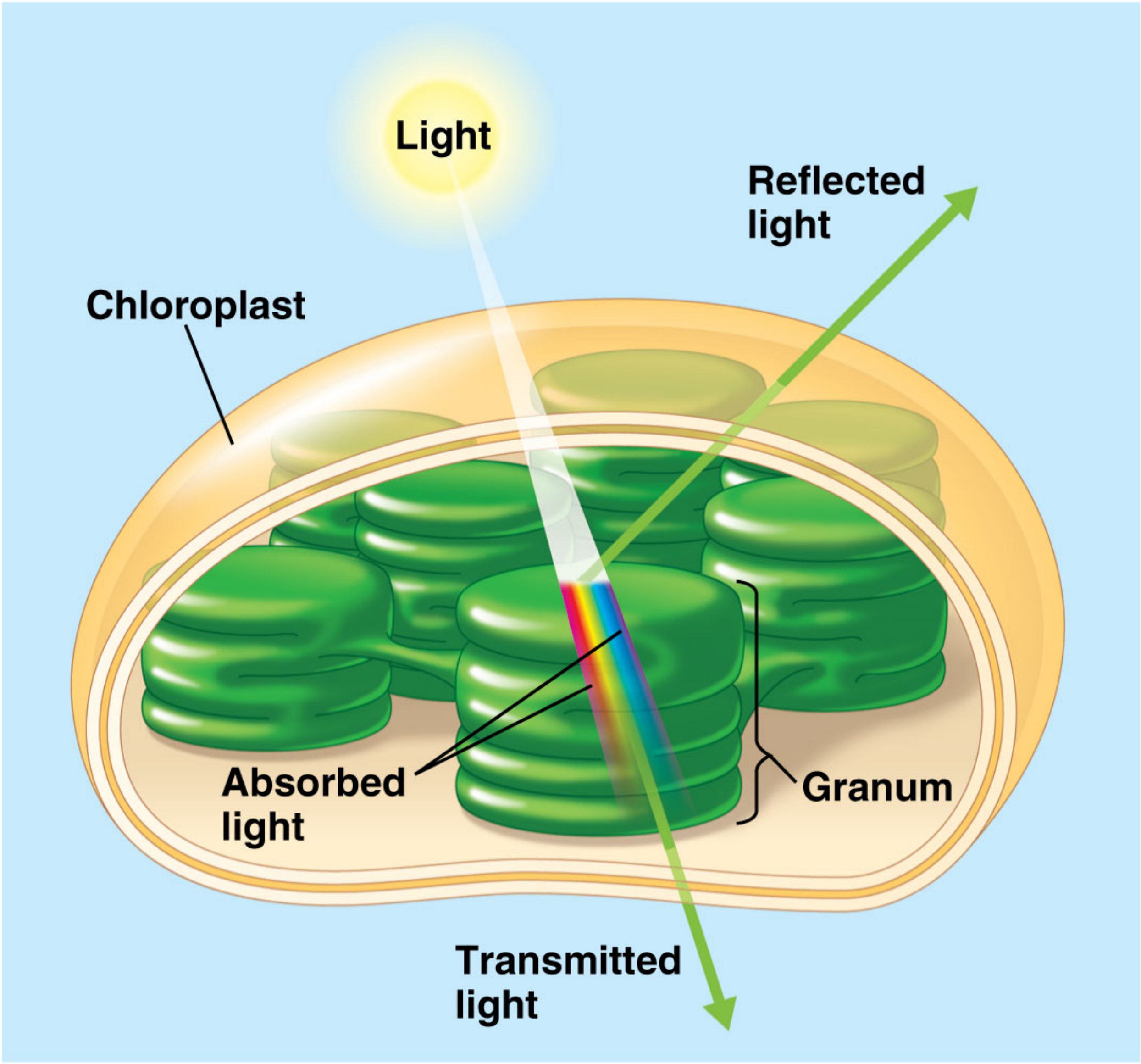
Nature of sunlight

- Light = Energy = electromagnetic radiation
- Shorter wavelength (λ): higher E
- Visible light - detected by human eye
- Light: reflected, transmitted or absorbed

Electromagnetic Spectrum



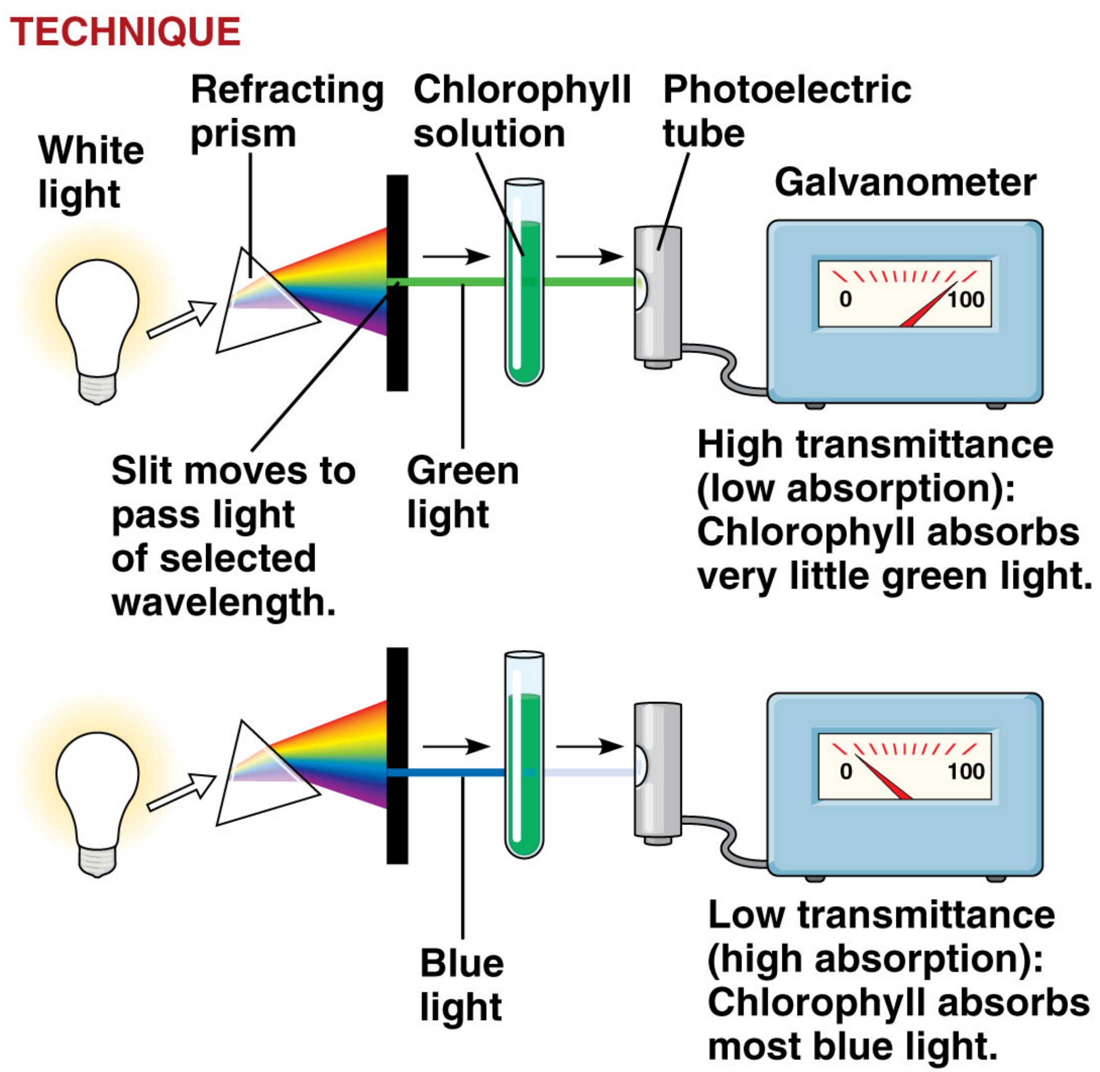
Interaction of light with chloroplasts



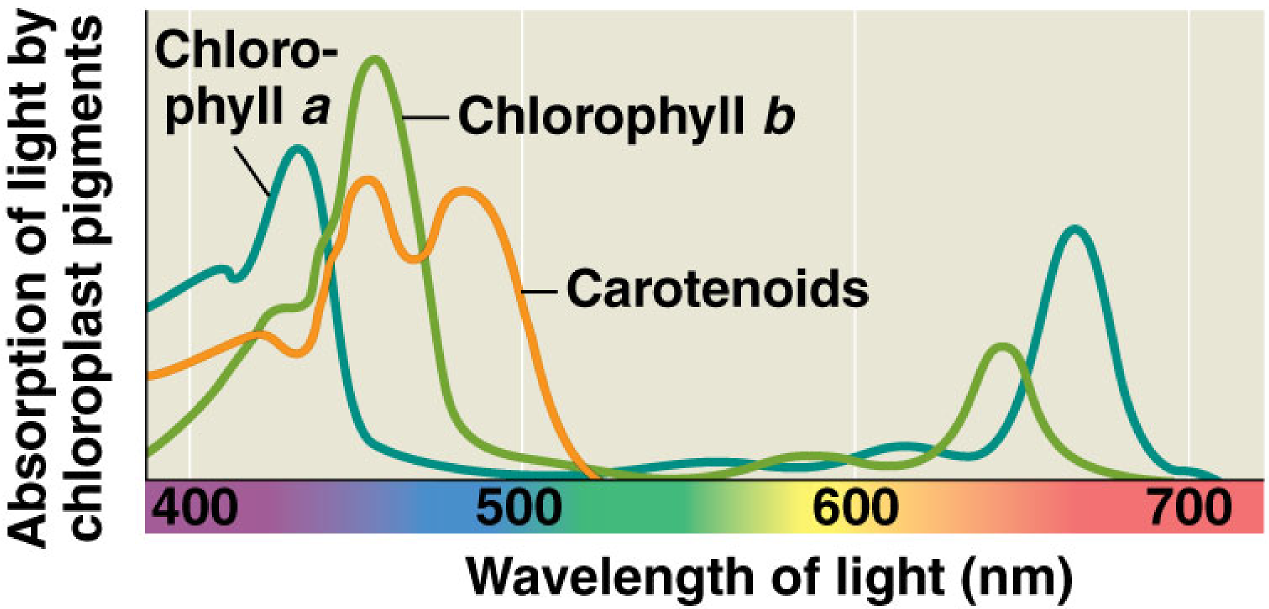
Photosynthetic pigments

- Pigments absorb different λ of light
- chlorophyll – absorb violet-blue/red light, reflect green
  - **chlorophyll a** (blue-green): light reaction, converts solar to chemical E
  - **chlorophyll b** (yellow-green): conveys E to chlorophyll a
  - **carotenoids** (yellow, orange): photoprotection, broaden color spectrum for photosynthesis

Absorption Spectrum: determines effectiveness of different wavelengths for photosynthesis



RESULTS



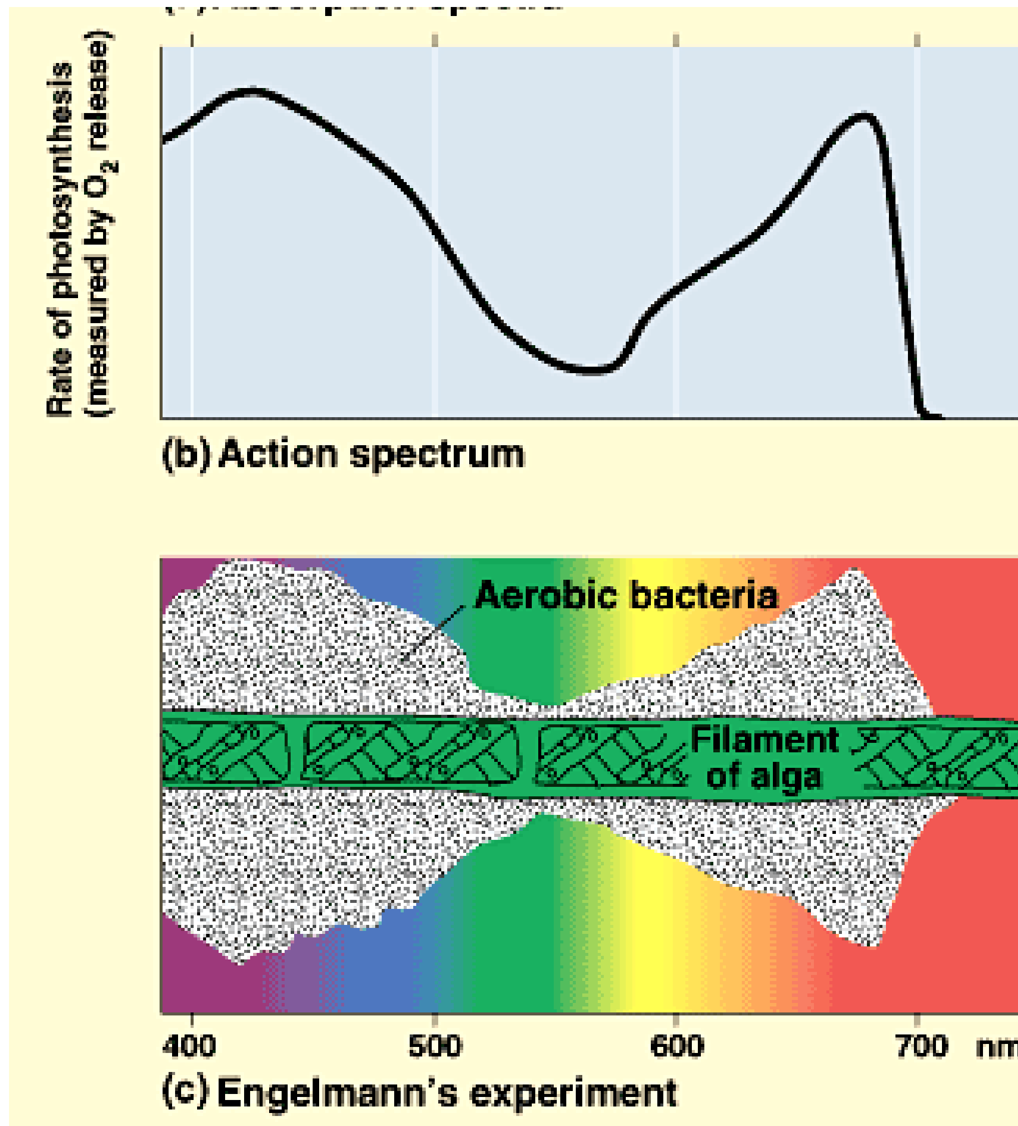
(a) Absorption spectra

Action Spectrum: plots rate of photosynthesis vs. wavelength

(absorption of chlorophylls a, b, & carotenoids combined)

Engelmann: used bacteria to measure rate of photosynthesis in algae; established action spectrum

Which wavelengths of light are most effective in driving photosynthesis?



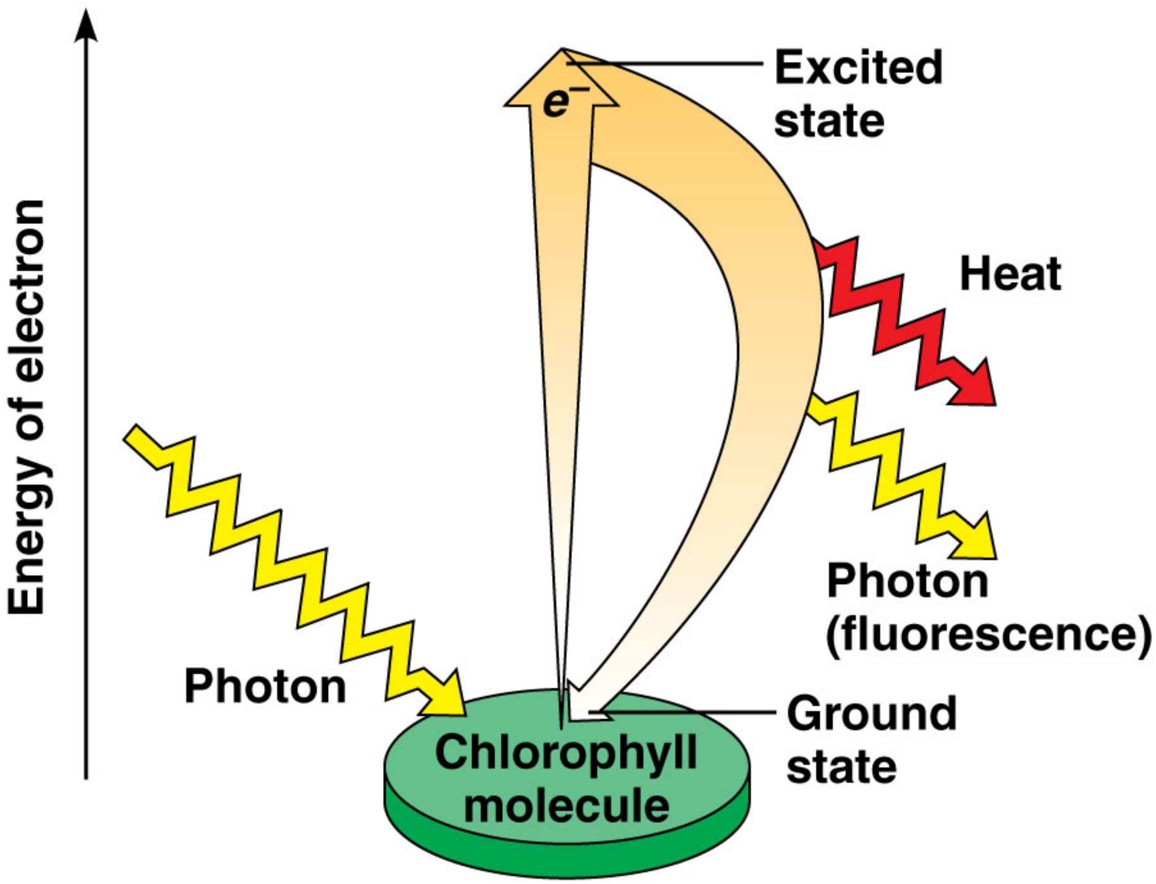
Warm-Up

1. What is the main function of the Light Reactions?
2. What are the reactants of the Light Reactions? What are the products?
3. Where do the Light Reactions occur?

Light Reactions

Section 8.2

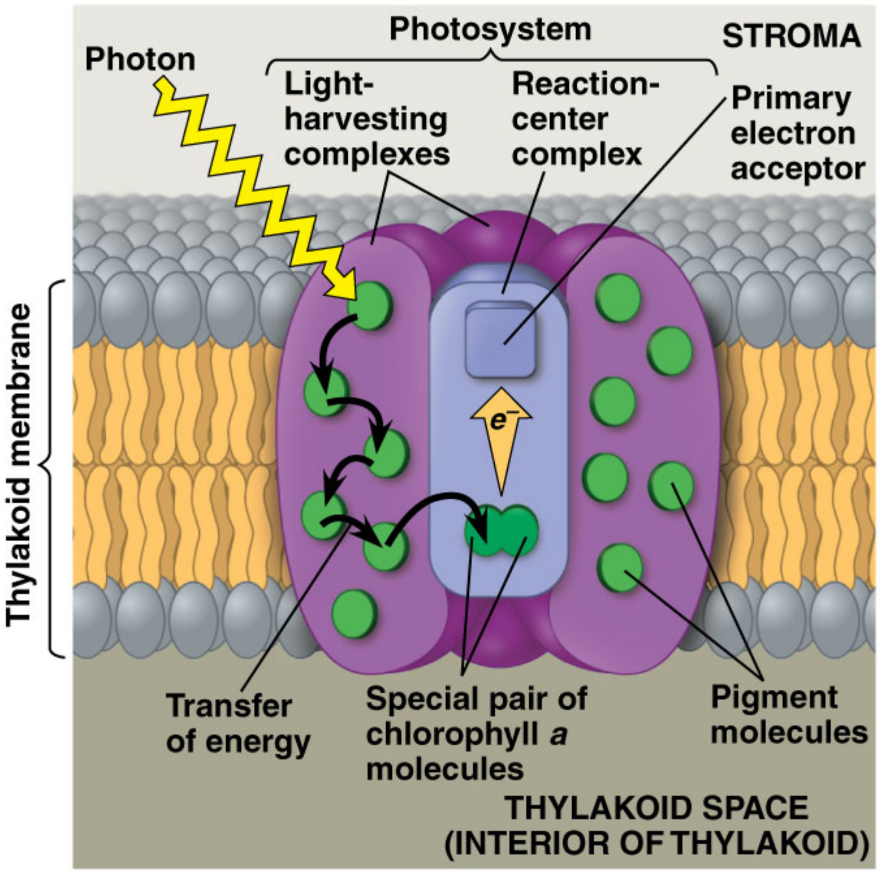
Electrons in chlorophyll molecules are excited by absorption of light



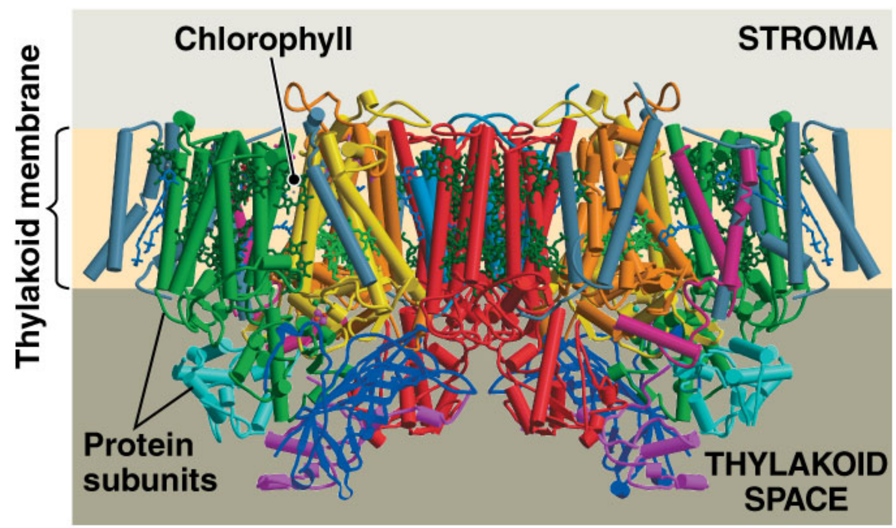
(a) Excitation of isolated chlorophyll molecule

(b) Fluorescence

Photosystem: reaction center & light harvesting complexes (pigment + protein)



(a) How a photosystem harvests light



(b) Structure of photosystem II

Light Reactions

Two routes for electron flow:

A. Linear (noncyclic) electron flow
B. Cyclic electron flow

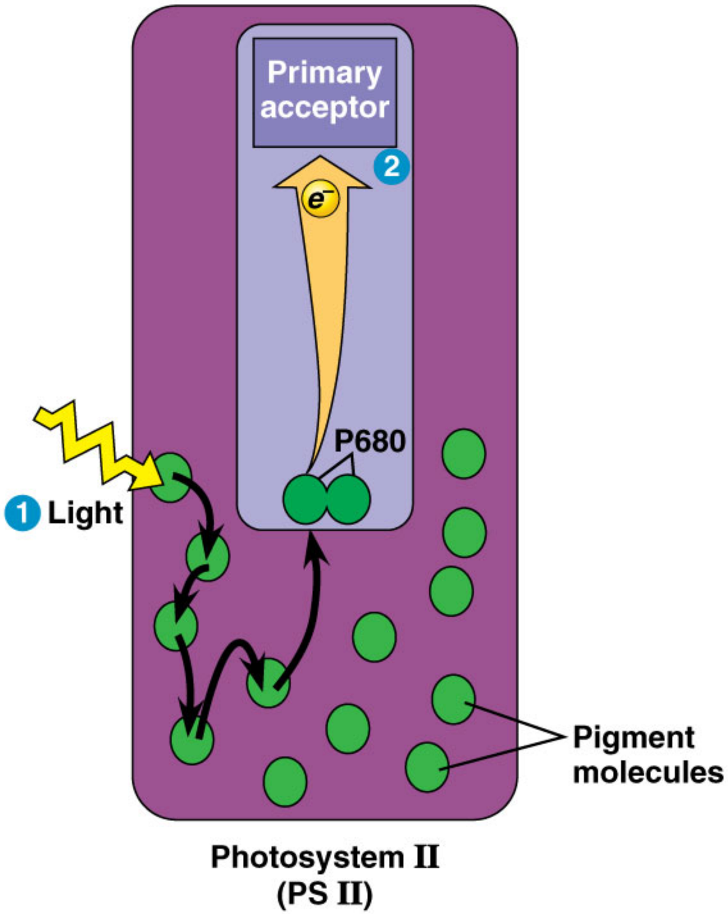
Light Reaction (Linear electron flow)

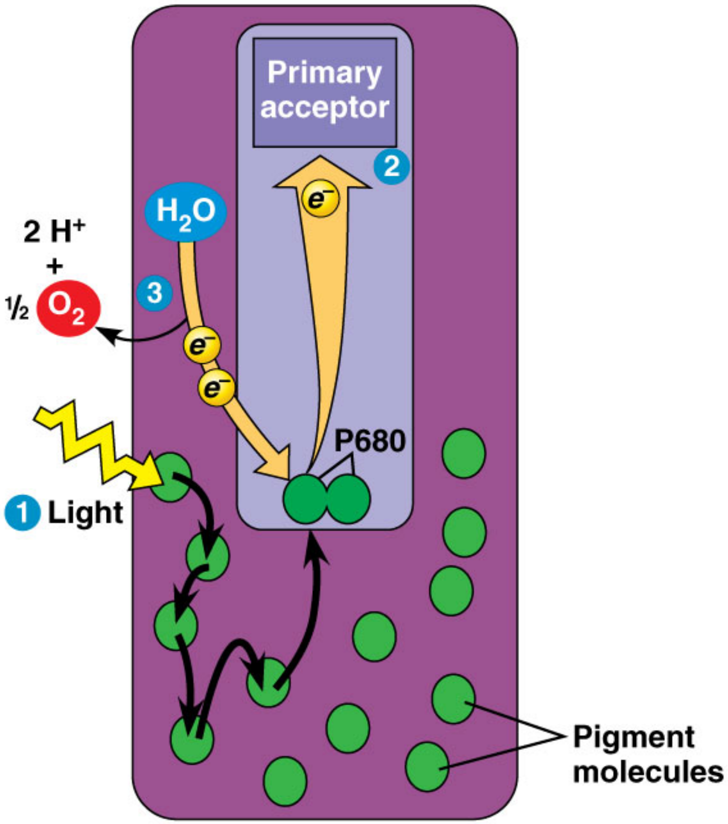
1. Chlorophyll excited by light absorption
2. E passed to reaction center of Photosystem II (protein + chlorophyll a)
3. e^- captured by primary electron acceptor
   - Redox reaction → e^- transfer
   - e- prevented from losing E (drop to ground state)
4. H_2O is split to replace e^- → O_2 formed

5. e^- passed to Photosystem I via ETC
6. E transfer pumps H^+ to thylakoid space
7. ATP produced by photophosphorylation
8. e^- moves from PS I's primary electron acceptor to 2^{nd} ETC
9. $NADP^+$ reduced to NADPH

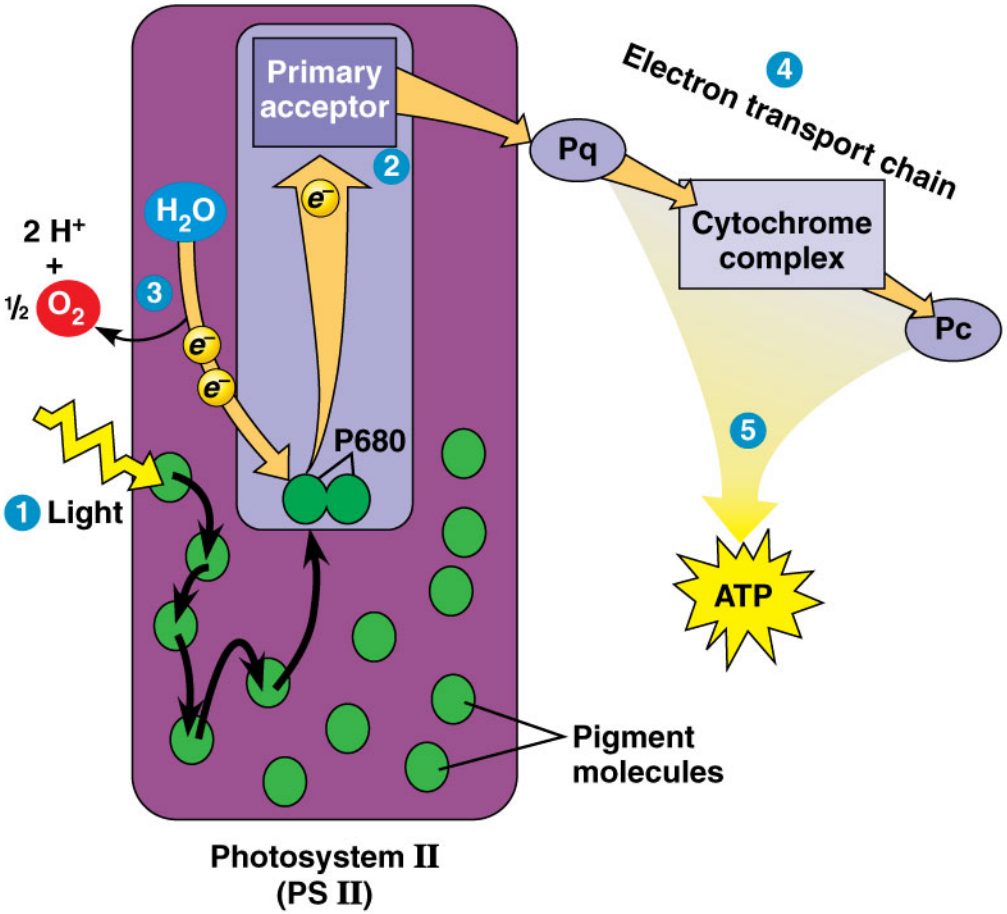
Main Idea:

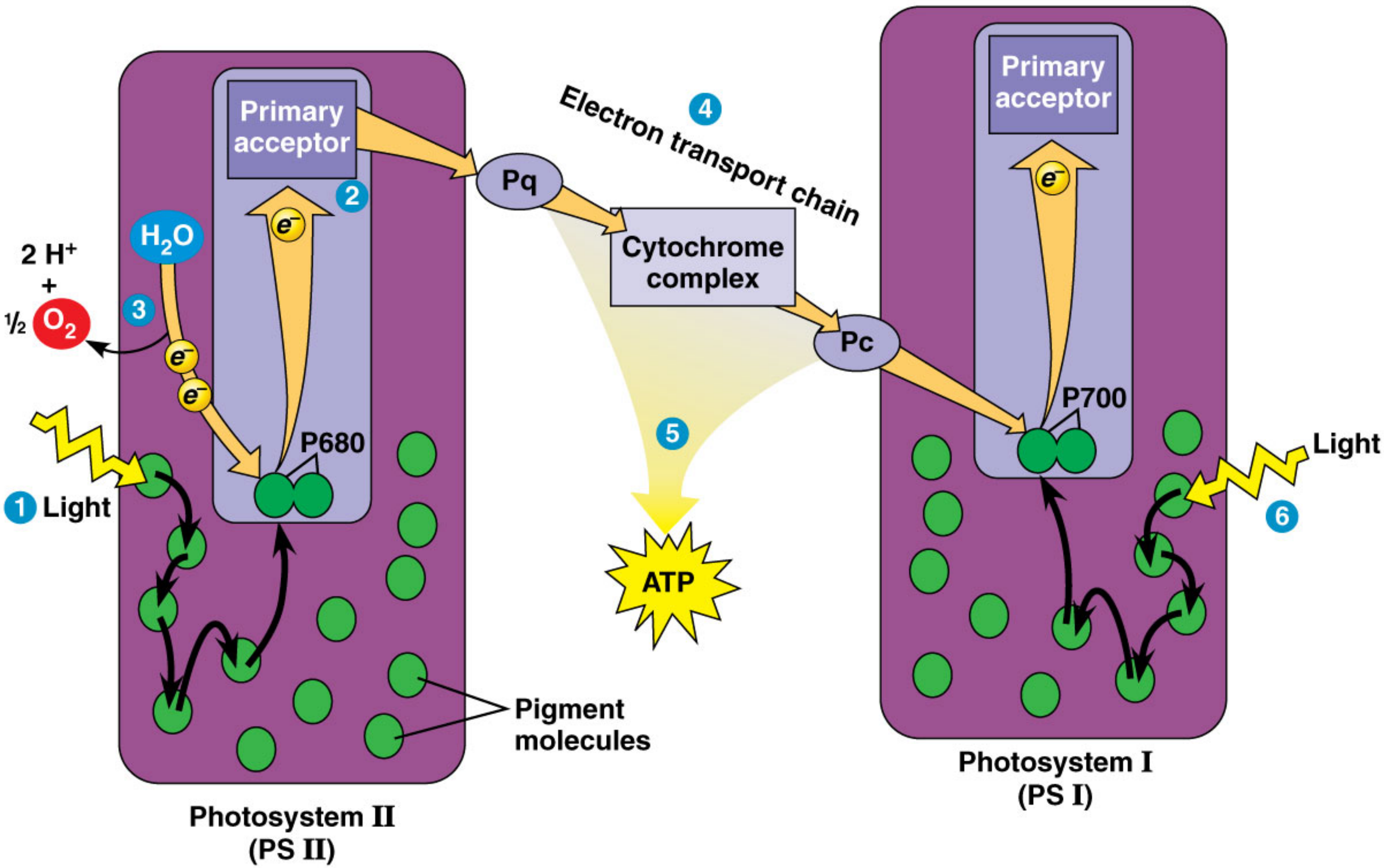
Use solar E to generate ATP & NADPH to provide E for Calvin cycle


Primary acceptor
2
e⁻
P680
1 Light
Pigment molecules
Photosystem II
(PS II)

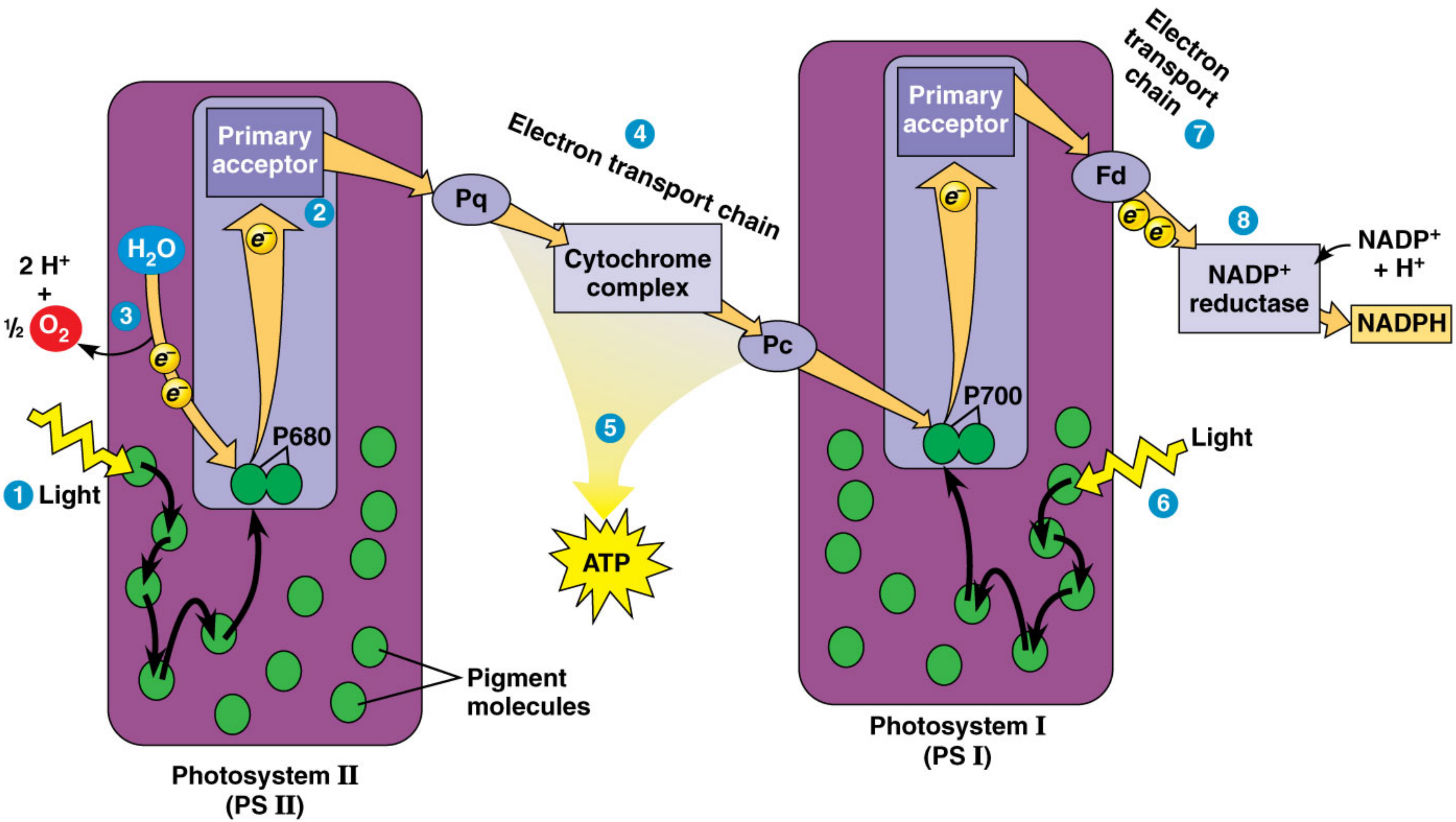


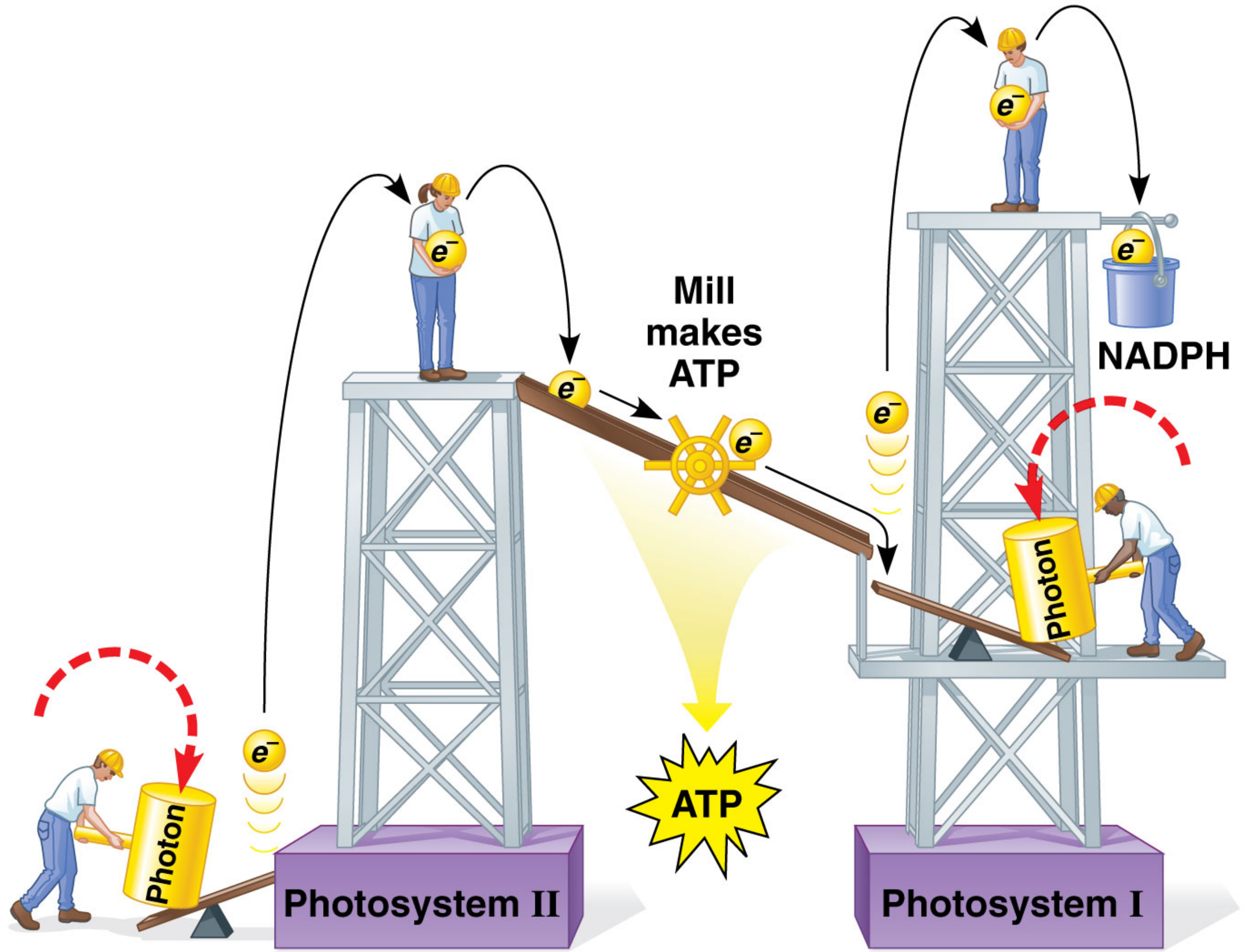
Photosystem II
(PS II)


Primary acceptor
2
e^-
H_2O
2 H^+
+
½ O_2
3
e^-
e^-
P680
1 Light
Pq
4
Electron transport chain
Cytochrome complex
Pc
5
ATP
Pigment molecules
Photosystem II
(PS II)



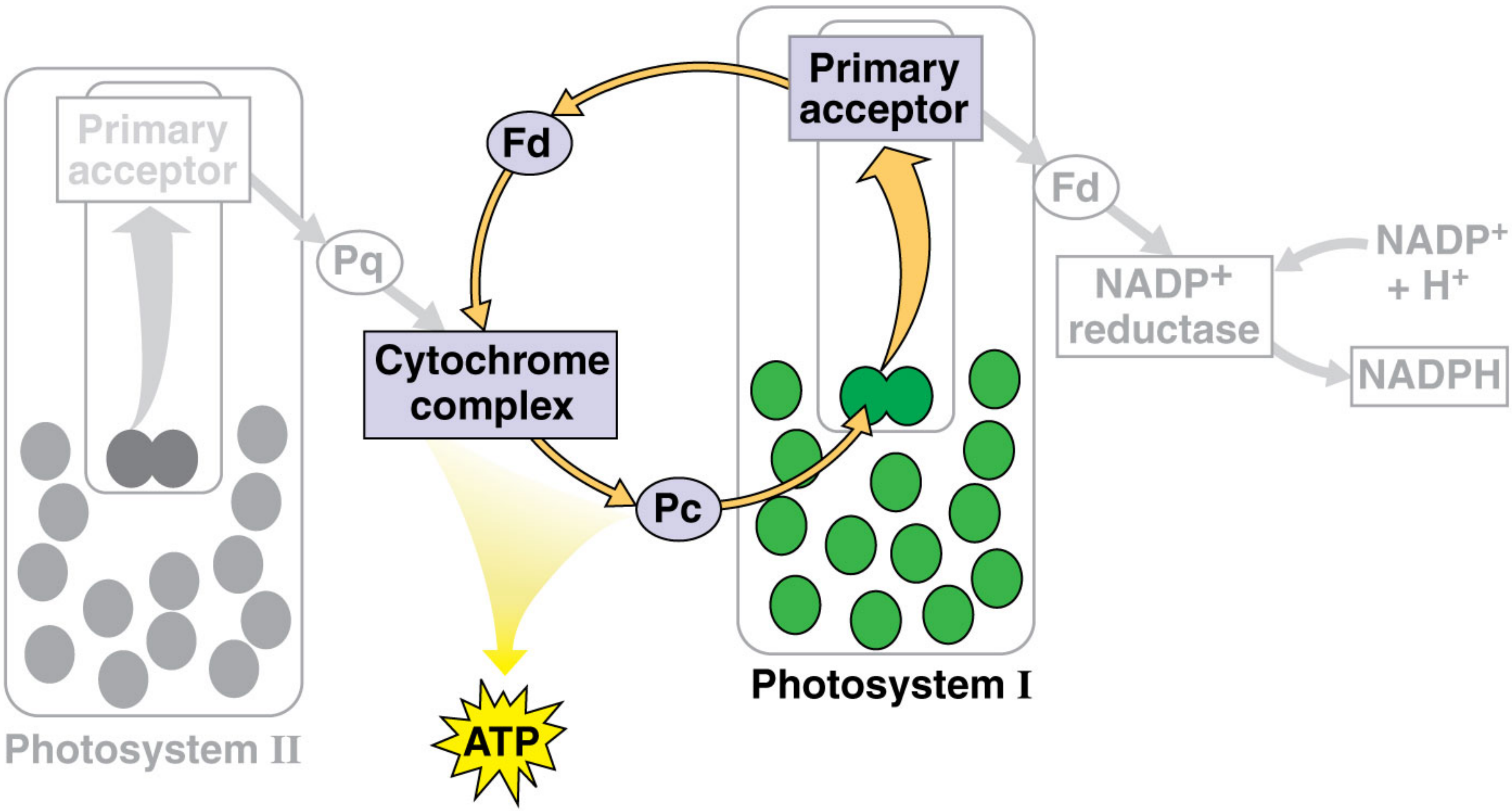
Primary acceptor
2
H2O
2 H+
+
½ O2
3
e−
P680
1 Light
Pigment molecules
Photosystem II (PS II)
Pq
4
Electron transport chain
Cytochrome complex
Pc
5
ATP
Primary acceptor
P700
Light
6
Photosystem I (PS I)


Electron transport chain
Electron transport chain
Primary acceptor
Primary acceptor
Pq
Cytochrome complex
Pc
Fd
NADP+ reductase
NADP+ + H+
NADPH
H2O
2 H+ + ½ O2
e−
P680
P700
Light
Light
ATP
Pigment molecules
Photosystem II (PS II)
Photosystem I (PS I)
1
2
3
4
5
6
7
8

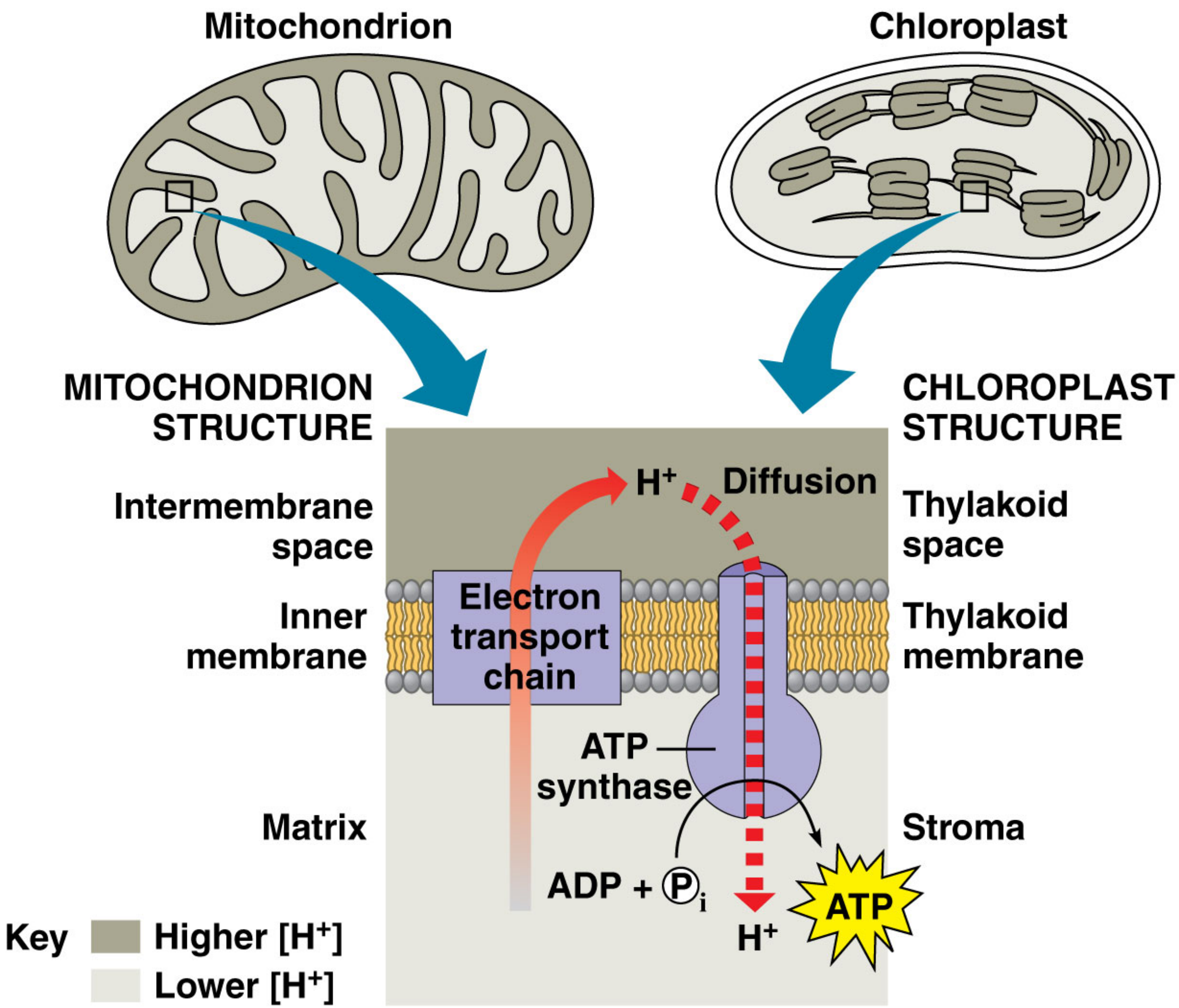


Mechanical analogy for the light reactions

Cyclic Electron Flow: uses PS I only; produces ATP for Calvin Cycle (no O_2 or NADPH produced)

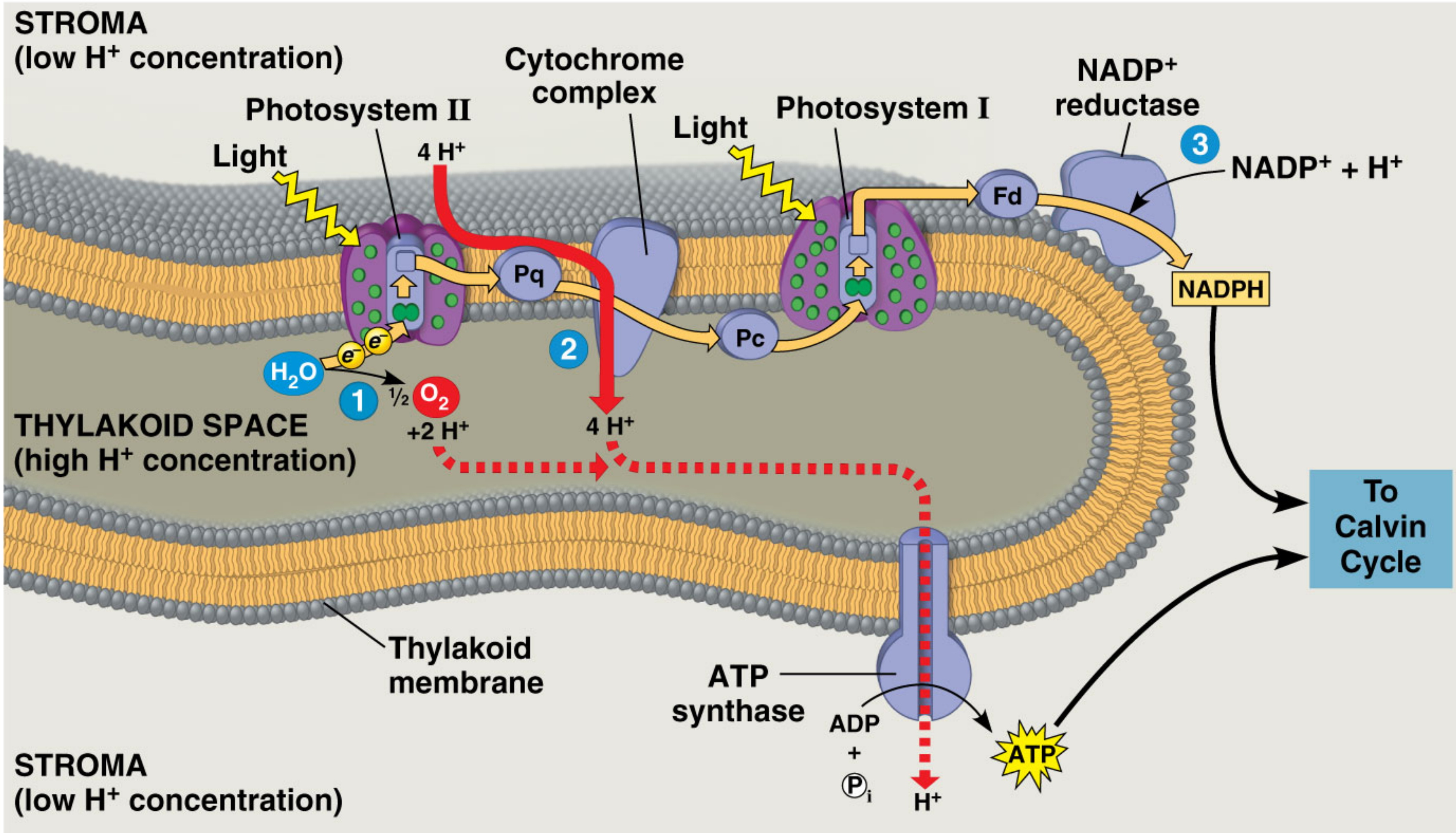


Both respiration and photosynthesis use <u>chemiosmosis</u> to generate ATP



Proton motive force generated by:

(1) H^+ from water
(2) H^+ pumped across by cytochrome
(3) Removal of H^+ from stroma when $NADP^+$ is reduced



Warm-Up

1. Write a short synopsis of the light reaction.
2. What is its function? Where does it occur?
3. (See Fig. 10.5) What products of the Light Reaction are used for the Calvin Cycle?

Calvin Cycle

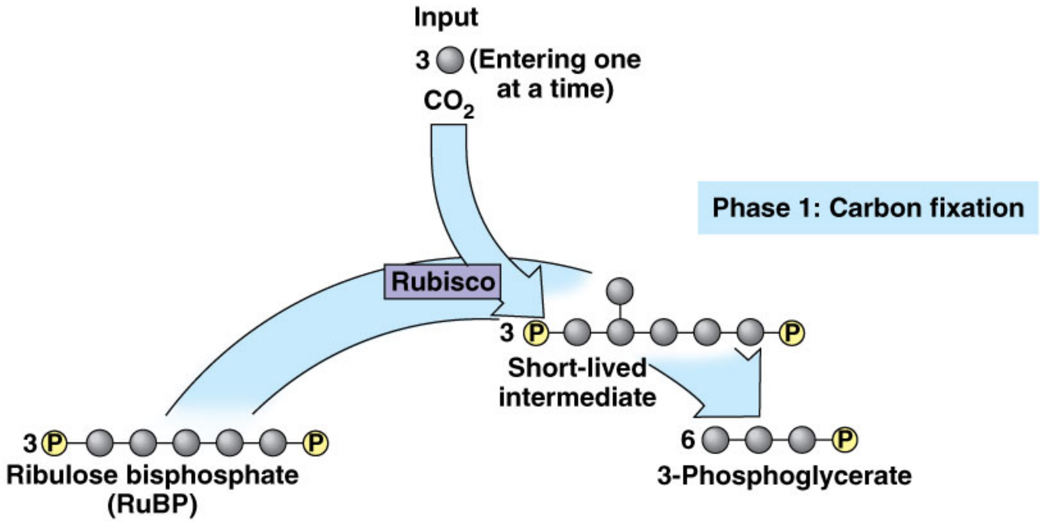
Section 8.3

Calvin Cycle: Uses ATP and NADPH to convert CO_2 to sugar

- Uses ATP, NADPH, CO_2
- Produces 3-C sugar G3P *(glyceraldehyde-3-phosphate)*

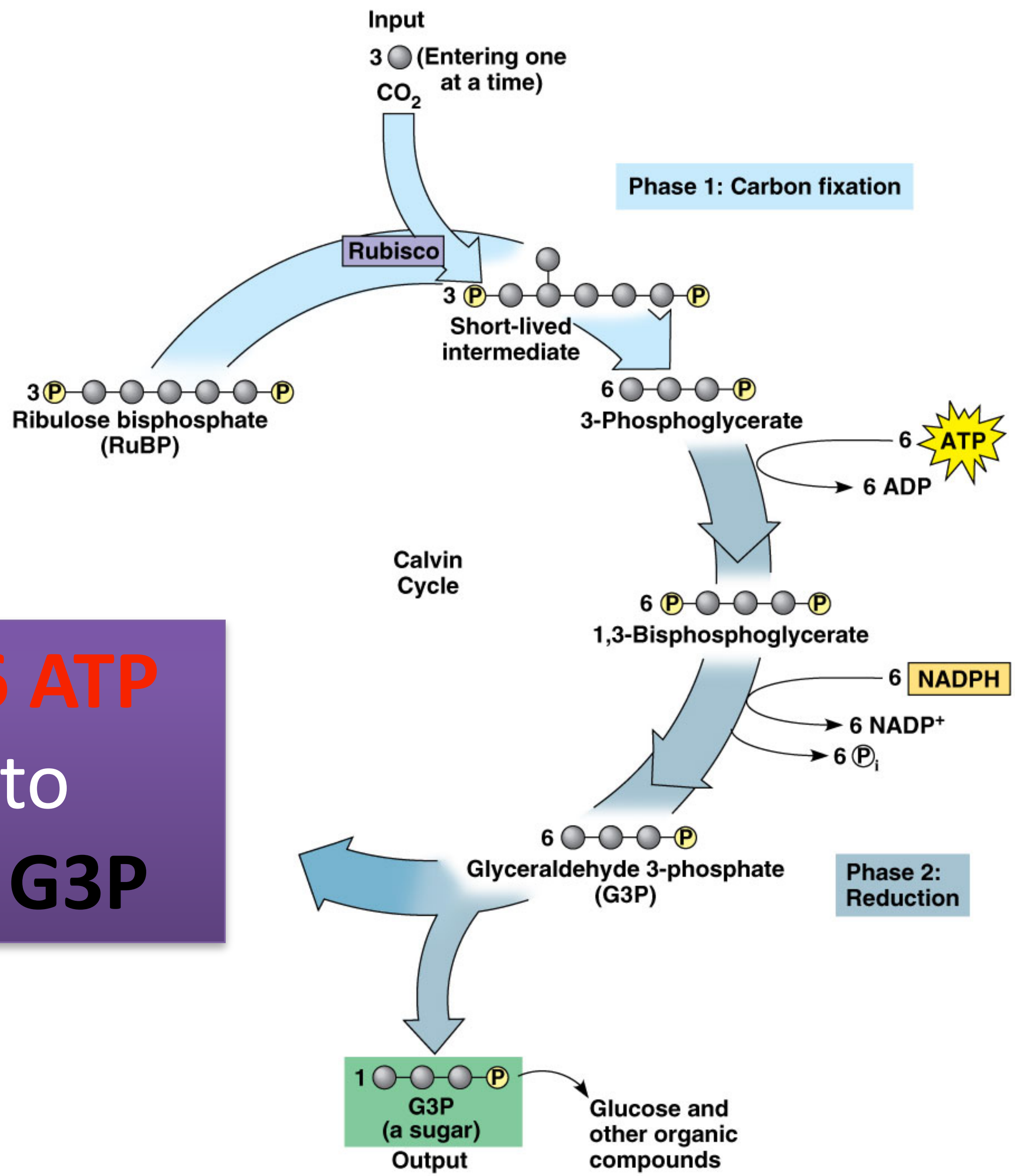
Three phases:

1. Carbon fixation
2. Reduction
3. Regeneration of RuBP (CO_2 acceptor)



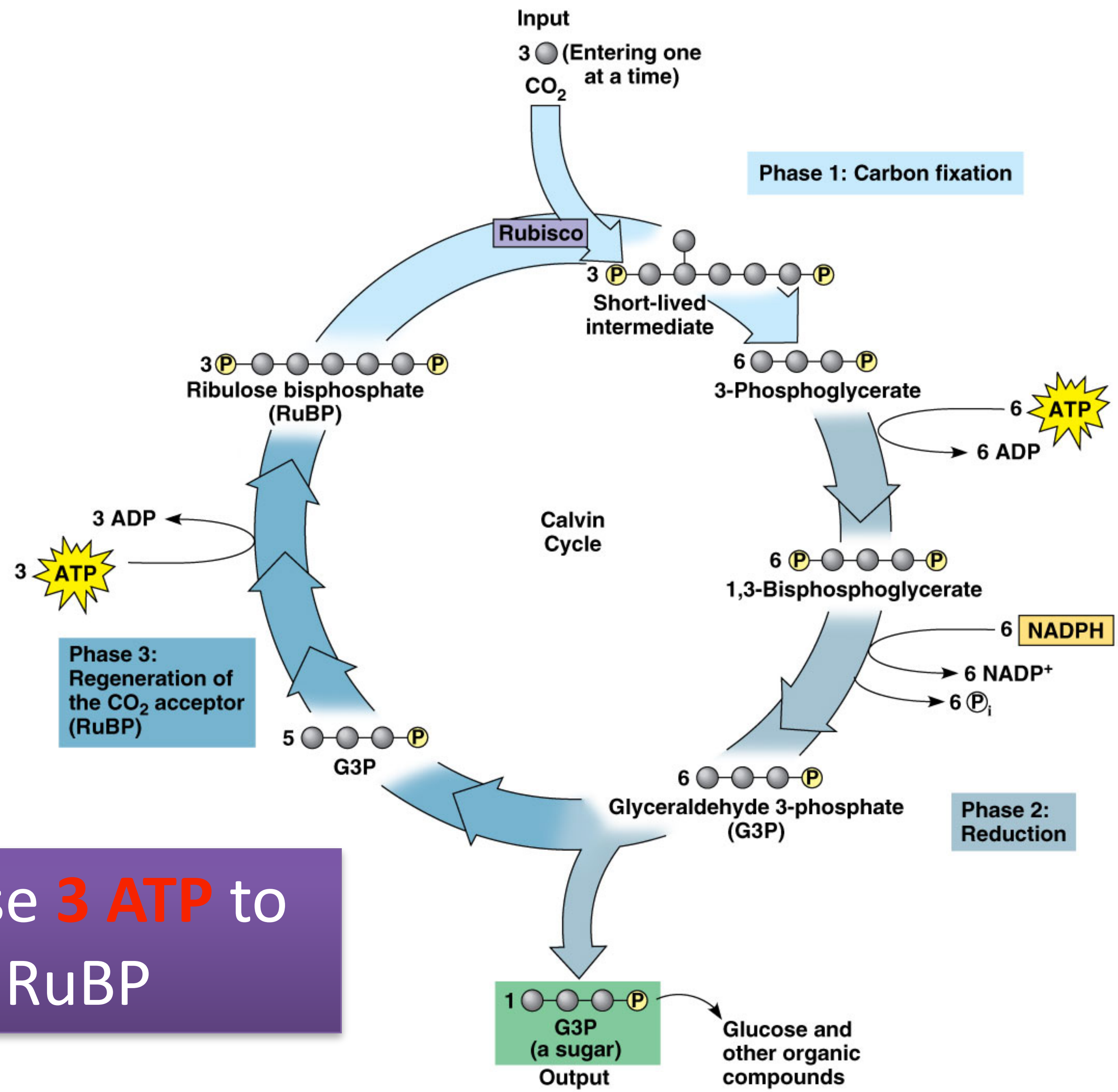
<u>Phase 1</u>: 3 CO_2 + **RuBP** (5-C sugar *ribulose bisphosphate)*

- Catalyzed by enzyme **rubisco** (*RuBP carboxylase*)



Phase 2: Use **6 ATP** and **6 NADPH** to produce 1 net **G3P**

Phase 3: Use 3 ATP to regenerate RuBP



Warm-Up

1. (See Figure 10.17) What are the 3 locations that H+ is used to create the proton gradient?
2. What purpose does cyclic e^- flow serve?
3. What is the main function of the Calvin Cycle? Where does it occur?
4. What are the reactants of the Calvin cycle? What are the products?
5. Which enzyme is responsible for carbon fixation?

Alternative mechanisms of carbon fixation have evolved in hot, arid climates

Photorespiration

- Metabolic pathway which:
  - Uses O_2 & produces CO_2
  - Uses ATP
  - No sugar production (rubisco binds O_2 → breakdown of RuBP)
- Occurs on hot, dry bright days when stomata close (conserve H_2O)
- Why? Early atmosphere: low O_2, high CO_2?

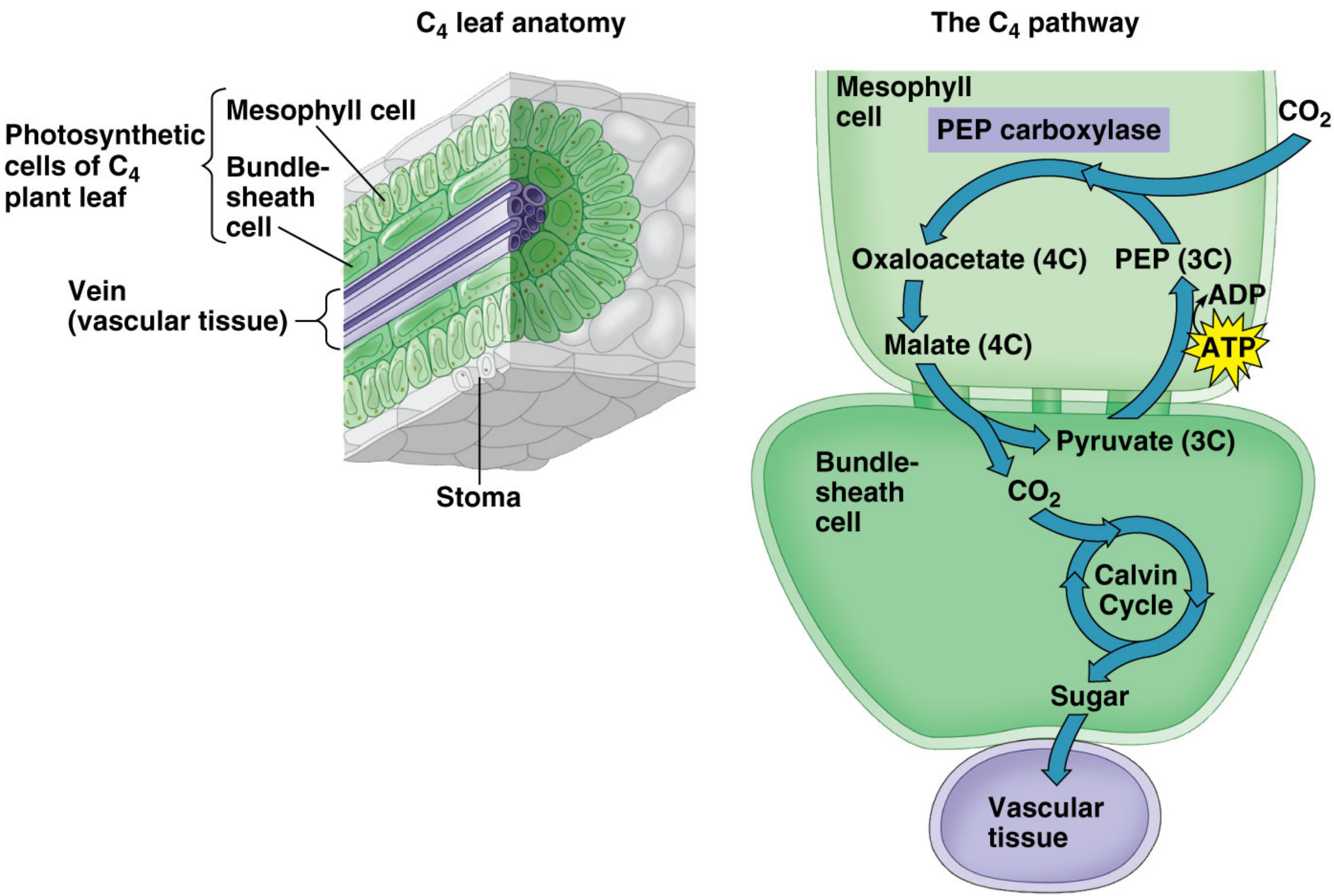
Evolutionary Adaptations

1. **Problem with C_3 Plants**:
   - CO_2 fixed to 3-C compound in Calvin cycle
   - Ex. Rice, wheat, soybeans
   - **Hot, dry days:**
     - partially close stomata, ↓CO_2
     - Photorespiration
     - ↓ photosynthetic output (no sugars made)

2. C_4 Plants:

- CO_2 fixed to 4-C compound
- Ex. corn, sugarcane, grass
- Hot, dry days → stomata close
  - 2 cell types = **mesophyll** & **bundle sheath** cells
    - mesophyll : PEP carboxylase fixes CO_2 (4-C), pump CO_2 to bundle sheath
    - bundle sheath: CO_2 used in Calvin cycle
- ↓photorespiration, ↑sugar production
- **WHY?** Advantage in hot, sunny areas

C_4 Leaf Anatomy



3. CAM Plants:

- *Crassulacean acid metabolism (CAM)*
- NIGHT: stomata open → CO_2 enters → converts to organic acid, stored in mesophyll cells
- DAY: stomata closed → light reactions supply ATP, NADPH; CO_2 released from organic acids for Calvin cycle
- Ex. cacti, pineapples, succulent (H_2O-storing) plants
- **WHY?** Advantage in arid conditions



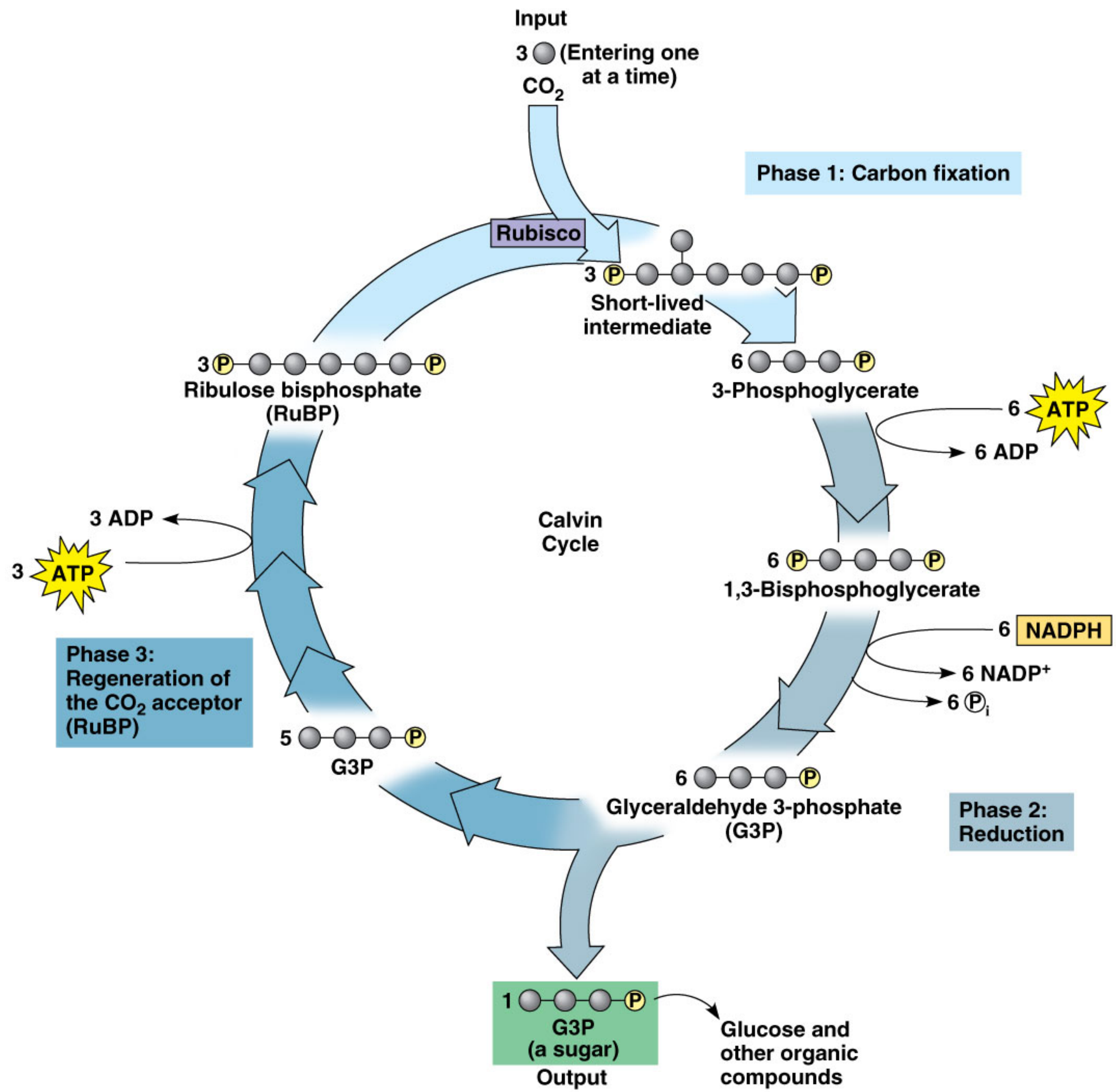
Warm-Up

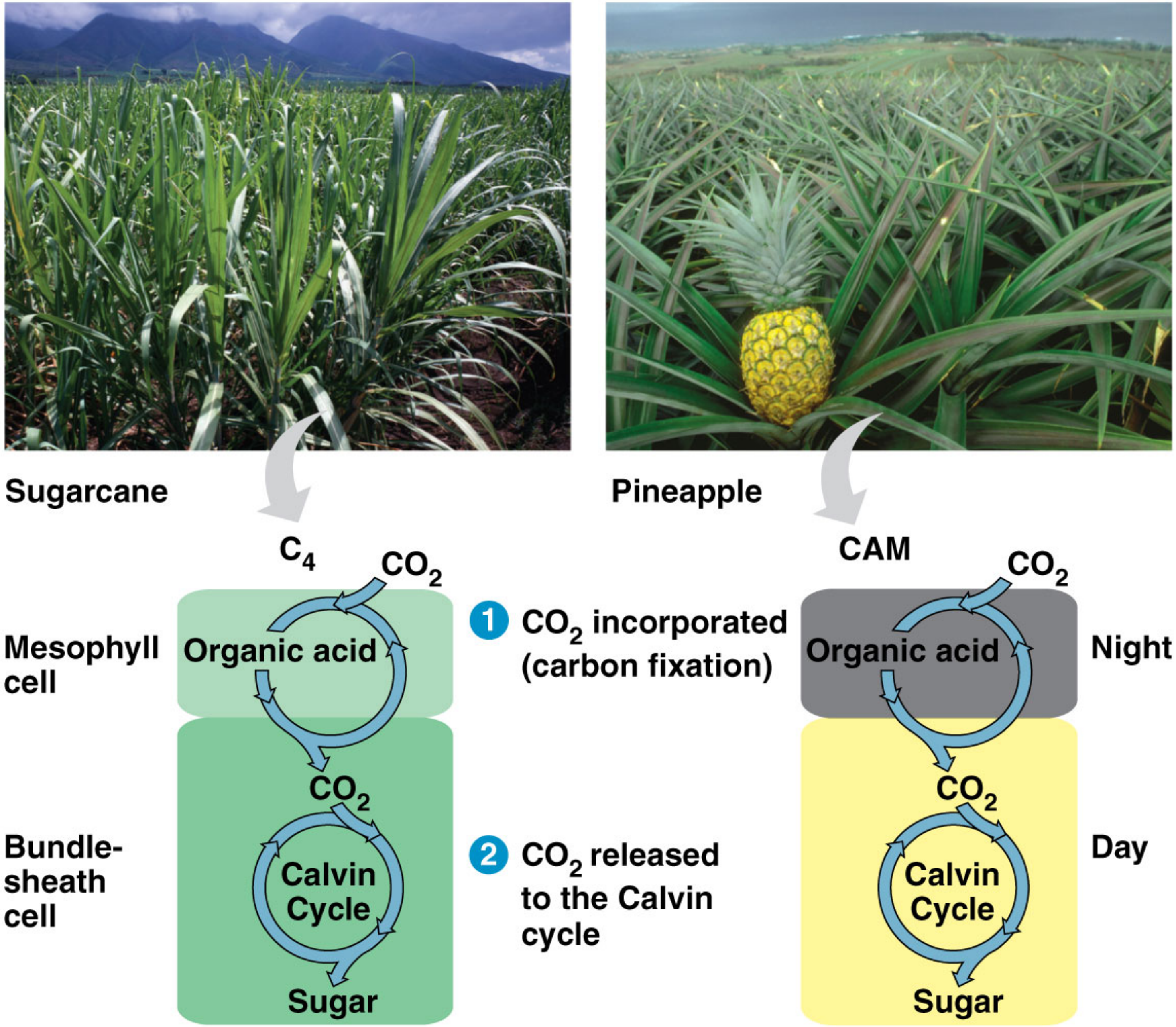
1. Draw a T-Chart. Compare/contrast Light Reactions vs. Calvin Cycle.

2. What is photorespiration? How does it affect C3 plants?

3. In lab notebook: Graph data from yesterday's lab. Determine the ET50 for the "With CO_2" test group.

4. In lab notebook: Brainstorm at list of possible factors that could affect the rate of photosynthesis. (Think of factors you could test with the leaf disk technique.)


Input
3 (Entering one at a time)
CO_2
Phase 1: Carbon fixation
Rubisco
3 P P
Short-lived intermediate
6 P
3-Phosphoglycerate
6 ATP
6 ADP
3 P P
Ribulose bisphosphate (RuBP)
3 ADP
3 ATP
Calvin Cycle
6 P P
1,3-Bisphosphoglycerate
6 NADPH
6 $NADP^+$
6 P_i
Phase 3: Regeneration of the CO_2 acceptor (RuBP)
5 P
G3P
6 P
Glyceraldehyde 3-phosphate (G3P)
Phase 2: Reduction
1 P
G3P (a sugar)
Output
Glucose and other organic compounds



(a) Spatial separation of steps

(b) Temporal separation of steps

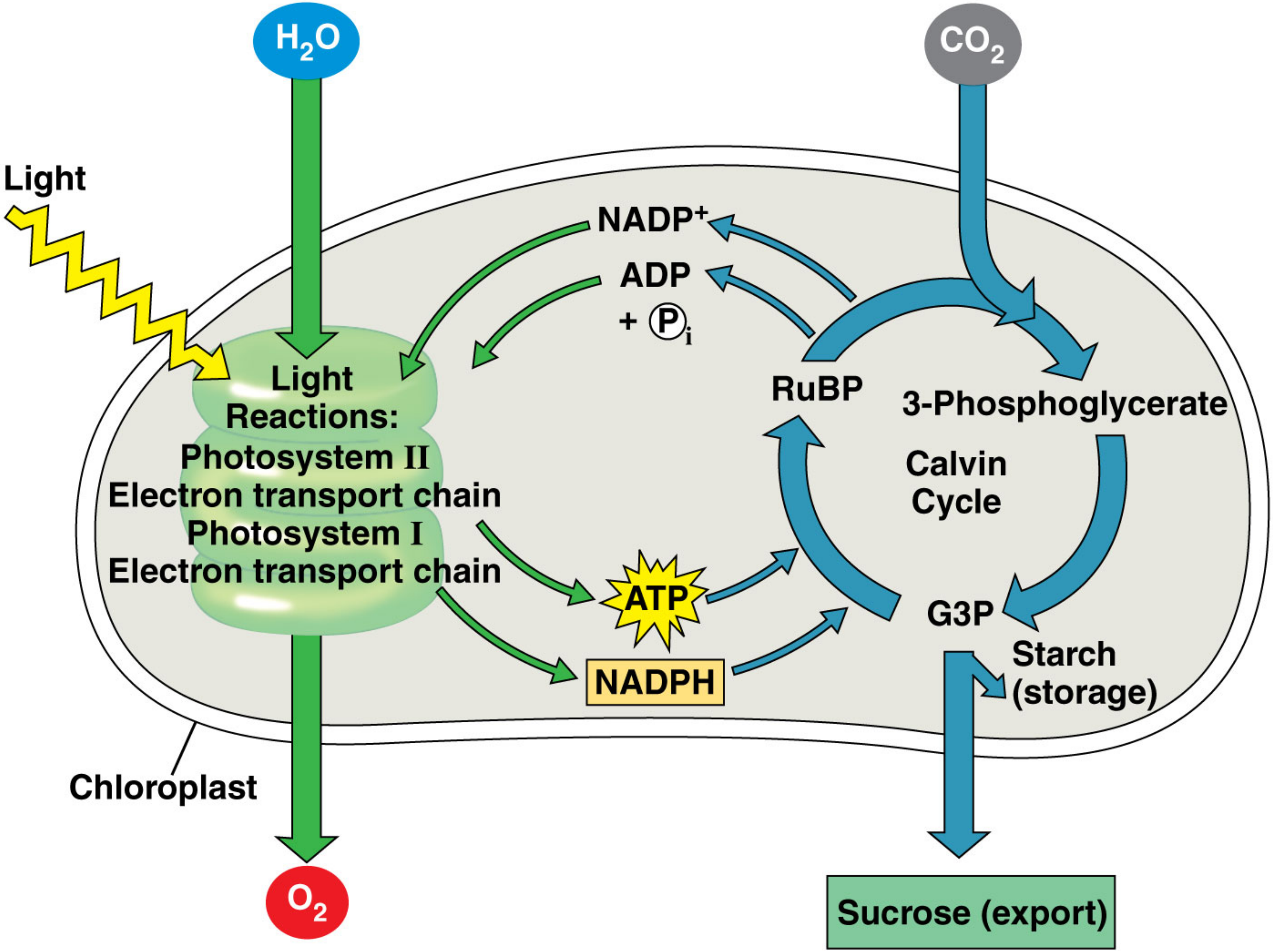
Comparison:

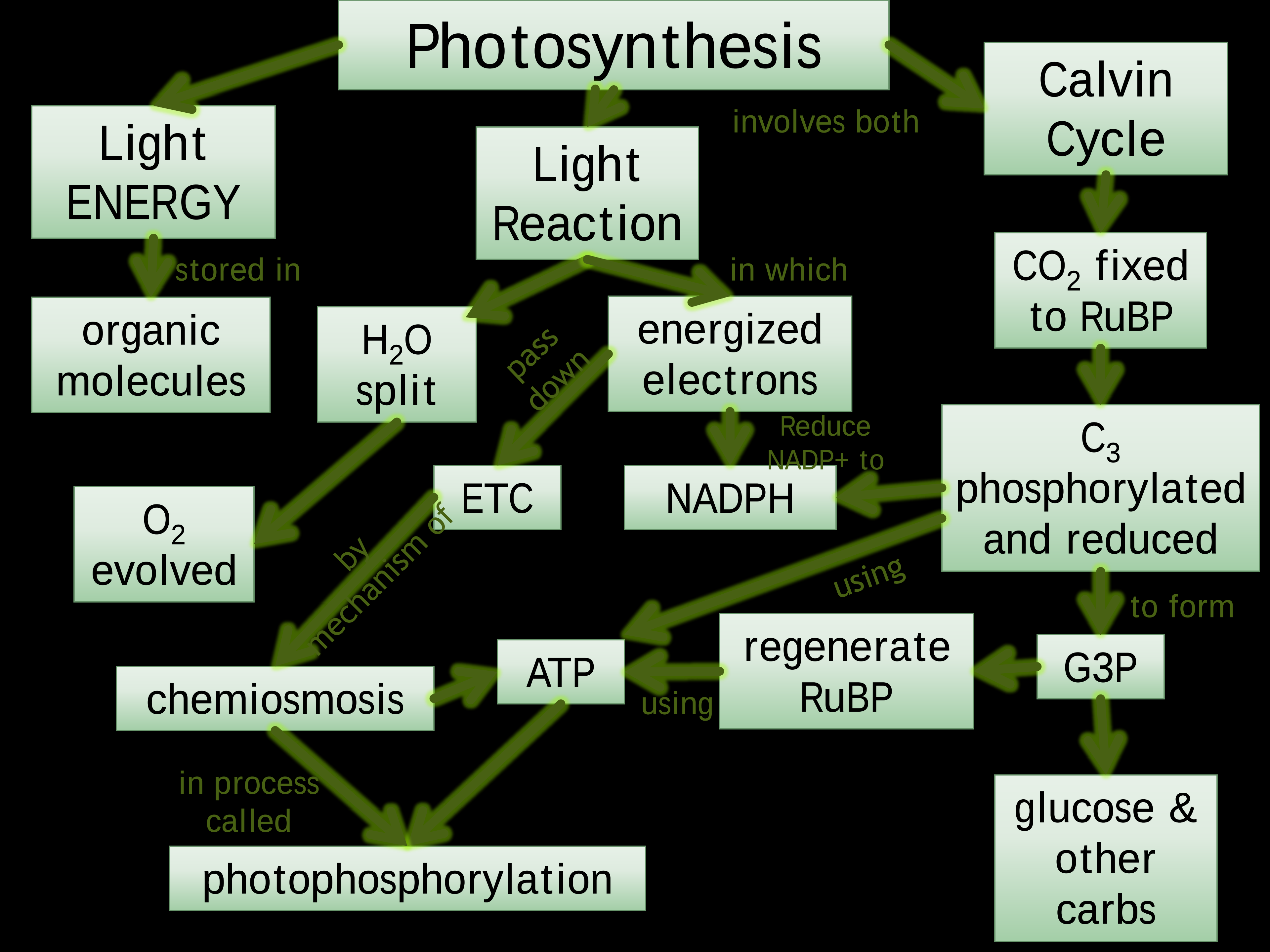
C_3	C_4	CAM
C fixation & Calvin together	C fixation & Calvin in different cells	C fixation & Calvin at different TIMES
Rubisco	PEP carboxylase	Organic acid

Importance of Photosynthesis:

Plant:	• Glucose for respiration • Cellulose
Global:	• O_2 Production • Food source

Review of Photosynthesis


H2O
CO2
Light
NADP+
ADP
+ Pi
Light
Reactions:
Photosystem II
Electron transport chain
Photosystem I
Electron transport chain
RuBP
3-Phosphoglycerate
Calvin
Cycle
ATP
NADPH
G3P
Starch
(storage)
Chloroplast
O2
Sucrose (export)


Photosynthesis
Light ENERGY
stored in
organic molecules
Light Reaction
involves both
Calvin Cycle
in which
H_2O split
pass down
energized electrons
CO_2 fixed to RuBP
O_2 evolved
ETC
Reduce NADP+ to
NADPH
C_3 phosphorylated and reduced
by mechanism of
using
to form
chemiosmosis
ATP
using
regenerate RuBP
G3P
in process called
photophosphorylation
glucose & other carbs

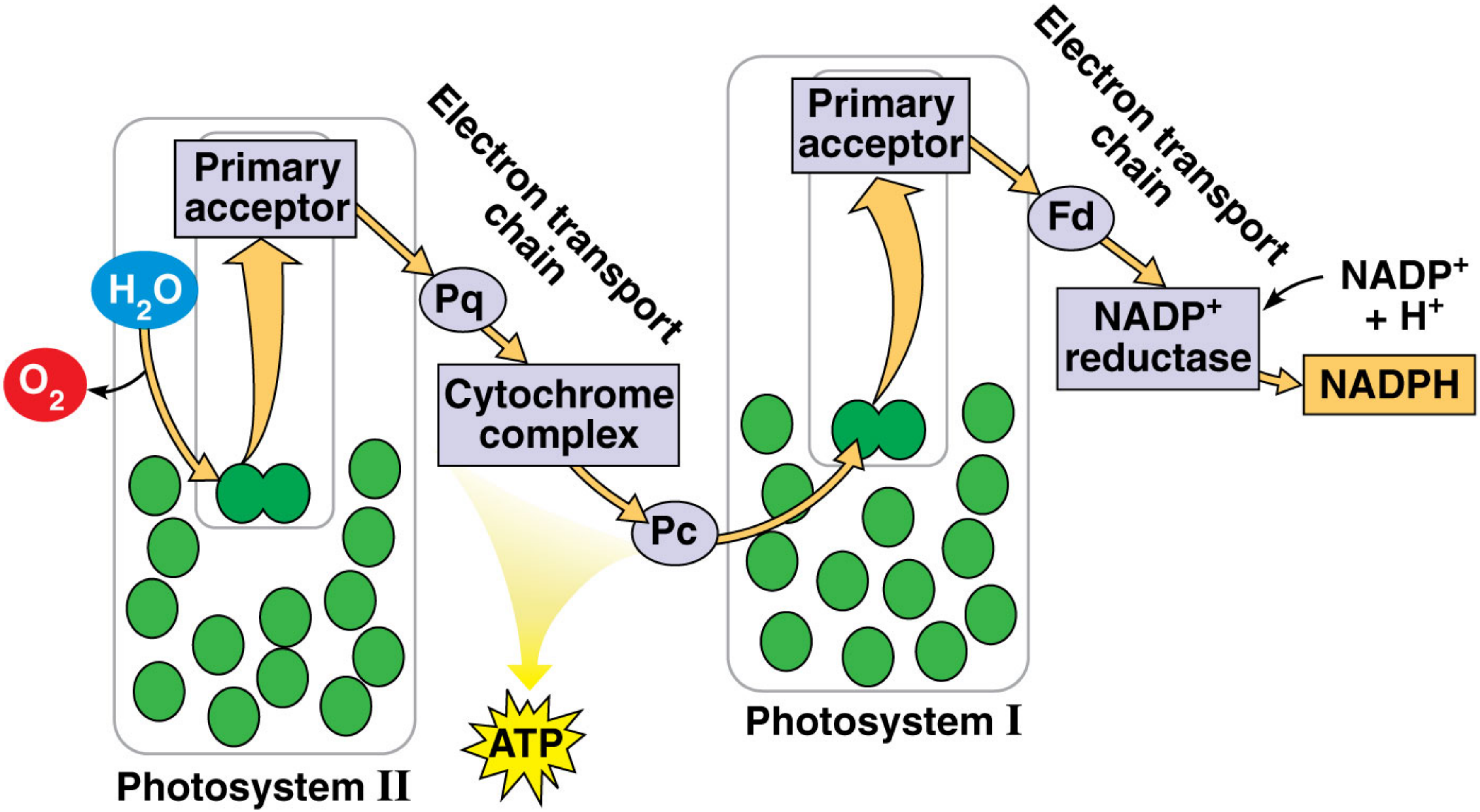
Comparison:

RESPIRATION

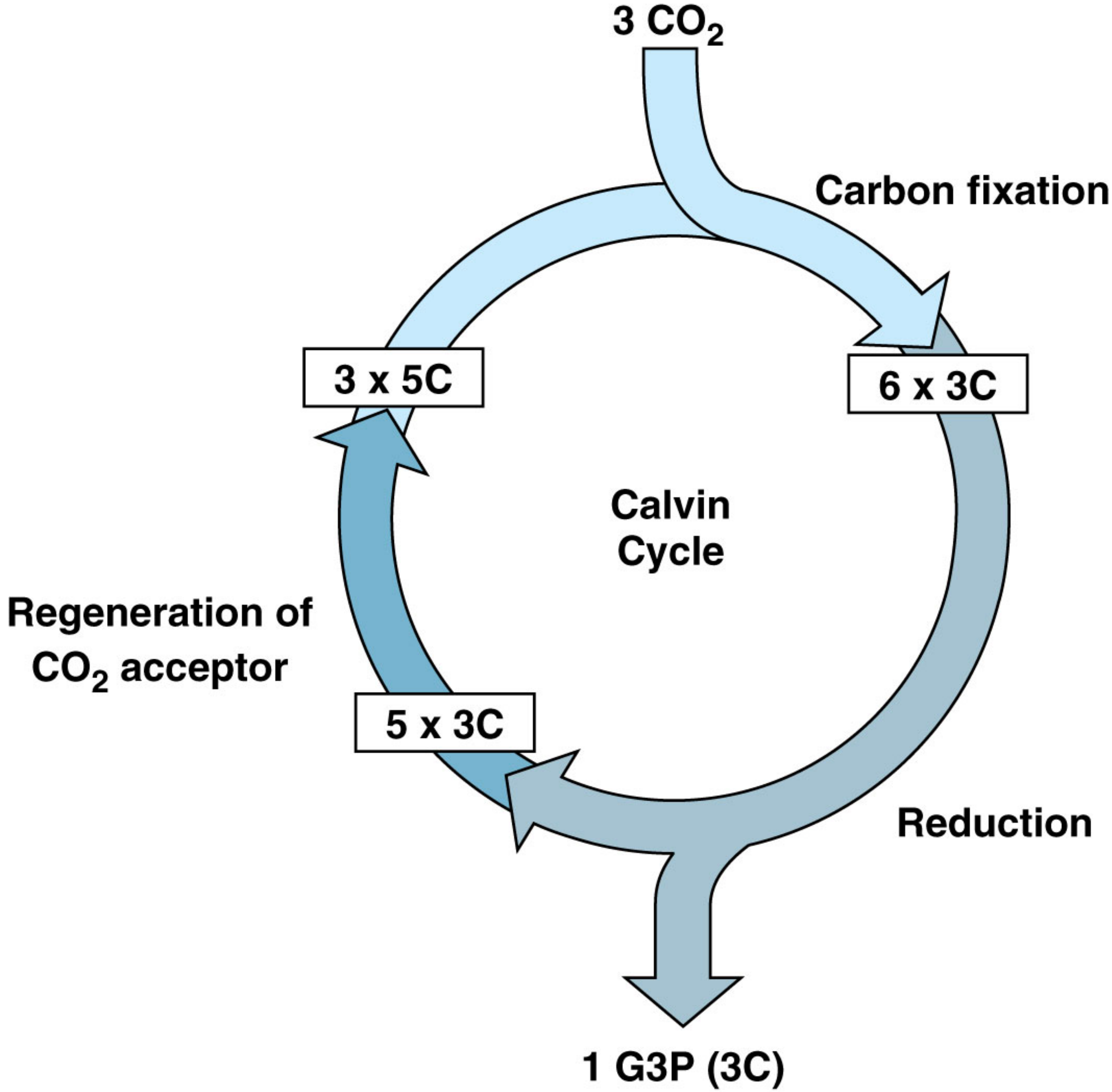
- Plants + Animals
- Needs O_2 and food
- Produces CO_2, H_2O and ATP, NADH
- Occurs in mitochondria membrane & matrix
- Oxidative phosphorylation
- Proton gradient across membrane

PHOTOSYNTHESIS

- Plants
- Needs CO_2, H_2O, sunlight
- Produces glucose, O_2 and ATP, NADPH
- Occurs in chloroplast thylakoid membrane & stroma
- Photorespiration
- Proton gradient across membrane



Primary acceptor
H2O
O2
Electron transport chain
Pq
Cytochrome complex
Pc
ATP
Photosystem II
Primary acceptor
Electron transport chain
Fd
NADP+ + H+
NADP+ reductase
NADPH
Photosystem I


3 CO_2
Carbon fixation
3 x 5C
6 x 3C
Calvin Cycle
Regeneration of CO_2 acceptor
5 x 3C
Reduction
1 G3P (3C)